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Assessing Lower Limb Strength, Power and Asymmetry in Elite Soccer Players using the Keiser Air420 Seated Leg Press

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ASSESSING LOWER LIMB STRENGTH, POWER AND ASYMMETRY IN ELITE SOCCER PLAYERS USING THE KEISER AIR420 SEATED LEG PRESS

JAMES REDDEN

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Health

October 2018

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ABSTRACT

Assessing lower limb strength, power and asymmetry in elite soccer players using the Keiser Air420 seated leg press

James Redden, University of Bath, 2018

In soccer, lower limb strength, power and bilateral asymmetry is considered a significant contributor to physical performance and injury risk. Therefore, the monitoring and testing of lower limb physical performance through a practical, applicable and reliable method is of paramount importance to practitioners. The Keiser Air420 seated leg press is a strength and power training and testing tool extensively used in elite soccer, however limited scientific research has been completed to support its use. The current thesis completed investigations to gain a greater understanding.

To provide a foundation for subsequent studies, initial research investigated the reliability of elite soccer players using the seated leg press across 3 consecutive trials. ‘Good’ reliability was established for all strength and power variables with bilateral asymmetry variables calculated around the average power values found to be the most reliable measures. Test-retest results also established limits of meaningful change for each variable to accurately evaluate change in longitudinal testing results.

Subsequently, typical characteristic lower limb values for an elite soccer player were established with an average bilateral power asymmetry of $4.3 \pm 4.1\%$ established. Centre Backs and Strikers were found to have ‘likely’ higher strength, power and asymmetry values than all other positions and U21 playing squad found to have higher Average Power Combined and Velocity Max Combined than the average of all players. Across a soccer season (July to April), the youngest professional squad (U17) showed ‘likely’ small increases in lower limb strength and power whilst U18 and U21 squads remained largely unchanged at all testing points. No significant variation in bilateral asymmetry was seen across a season for any playing squad. When assessing seated leg press performance around match play, no differences in lower limb performance were found immediate post-match with ‘possible’ decreases seen in Peak Power Combined at 24 h post-match when an obvious outlier was excluded. Although no clear differences were seen in bilateral asymmetry, 5 of 19 participants notably

increased their asymmetry values both immediately post-match and at 24 h post-match suggesting large individual variation in response of lower limb strength, power and asymmetry following match participation. Limited effects were seen when comparing pre-season strength, power and bilateral asymmetry values and overall season-long injury incidence. However, clear ‘likely’ and ‘very likely’ harmful effects were seen for increased strength and power variables in relation to injury burden across a season suggesting that stronger, more powerful individuals are at no greater risk of injury incidence but are likely to suffer a greater injury burden if injury occurs.

This thesis has provided the applied practitioner with greater confidence and detail regarding the testing of elite soccer players using the Keiser Air420 seated leg press. The identification of typical characteristic values, limits of meaningful change around variables and parameters associated with increased injury burden enable practitioners to use the testing protocol with elite soccer players with greater confidence whilst also gaining greater insight into results found.

PUBLICATIONS

Redden, J., Stokes, K. and Williams, S. (2018). Establishing the reliability and limits of meaningful change of lower limb strength and power measures during seated leg press in elite soccer players. *Journal of Sports Science and Medicine*. 17, 539-5

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CHAPTER 1: GENERAL INTRODUCTION

Soccer, nicknamed ‘the beautiful game’, is the most popular sport in the world. There are an estimated 3.5 billion fans worldwide with approximately half of the world’s countries ranking it as their most popular sport. According to FIFA, over 1 billion people watched the 2014 World Cup Final and, in their ‘Big Count’ survey (2006), it was stated that 265 million people, approximately 4% of the world’s population, are actively involved in soccer in some capacity (Kunz, 2007).

Within professional soccer, the ‘top 5’ leagues across Europe (England, Germany, Spain, France and Italy) are the most popular, with the English Premier League the most watched league, being broadcast to 212 different territories across the world. Without a doubt, the individuals playing within these top 5 leagues (approximately 2,450 players) are at the very elite end of the spectrum, representing the top 99.999999% of the estimated total participants worldwide.

Due to the popularity of the sport, the finances within the industry are also significant. Across the 2015-16 soccer season, estimated revenue across all European soccer markets reached a record high of £22 billion, with the Premier League revenue alone calculated at £3.6 billion. At an individual club level, in the 2016-17 season, Manchester United generated the highest revenue of all professional soccer clubs with an estimated £581m and 10 English Premier League clubs ranked within the top 20 highest-earning clubs in the world. Across Europe, due to how the distribution of money is organised, it is clear that success brings increased wealth for any individual club. However, regardless of the financial implications, success, qualified by winning matches, leagues and trophies, should be the ultimate goal for any soccer team.

Determinants of success in soccer are extensive and difficult to quantify, however two modifiable factors that have been found to correlate with overall team success are high levels of physical performance (Rampinini et al., 2009; Arnason et al., 2004; Wisloff et al., 1998) and maintenance of high squad availability/reduction in injury incidence (Hagglund et al., 2013; Carling et al., 2015). Soccer is a high-intensity intermittent sprint sport involving repeated explosive efforts, which often contribute to the significant moments in a match. It has been found that more successful teams, classified by league position, complete more of these actions at the required intensity across a match, suggesting that superior levels of physical capacity are associated

with improved team success (Rampinini et al., 2009). Correlations have also been found between lower injury burden/higher match availability and increased points per match and higher final league ranking (Hagglund et al., 2013), suggesting that if a manager and/or coaching team have a higher number of players to pick from for any given match, across a season, the likelihood of success is also greater. Aside from team success, injuries in soccer have a large financial implication upon a soccer club, with JLT Speciality (2017) estimating that any one injury may cost a premier league team approximately £300,000 with each Premier League club spending, on average, £8,850,000 on injured players during the 2016-17 season. Therefore, for both team success and financial optimisation, physical performance enhancement and injury incidence reduction are two modifiable factors that can be prioritised within a soccer club.

In an attempt to assist in planning for optimal team physical performance and reduction of injury incidence, investment in sports science support in elite soccer has grown significantly over the past 30 years with Sir Alex Ferguson calling it ‘the biggest and most important change in my lifetime’ (Walker, 2003). Indeed Reilly and Williams (2004) note:

‘In the 1980s, it became apparent that the football industry and professionals in the game could no longer rely on the traditional methods of previous decades...Methods of science were applied to organising the big soccer clubs and the training of players could be formulated on a systemic basis. In general, the clubs that moved with the time were rewarded with success by gaining advantage over those that did not change.’

In 2018, the role of a sports scientist within football should be to ‘scientifically monitor elite players, for fitness, strength, agility, nutrition, workload and recovery’ (Kennedy and Kennedy 2016) and subsequently relay this information to the medical department and coaching staff to assist in making informed decisions regarding training and match play. As the physical demands of soccer match play continually increase (Barnes et al., 2004), the requirement for detailed athlete monitoring and physiological preparation to ensure optimal performance and injury prevention also increase.

A significant contributor to physical performance and injury risk reduction in elite soccer is lower limb strength, power and bilateral asymmetry (Orchard et al., 1997; Croisier et al., 2008; van Beijsterveldt et al., 2013). Indeed, lower muscular strength has been consistently associated with an increased injury incidence (Ekstrand and Gillquist 1983; Soderman et al., 2001; Engebretsen et al., 2010) and increases in muscular strength have been found to correlate with reduced injury incidence (Heidt et al., 2000; Askling et al., 2003). Although adequate muscular strength appears to be protective of injury, individuals with superior power output capability have been found at a greater risk of injury as have individuals with large bilateral power asymmetries (Henderson et al., 2010; Engebretsen et al., 2010; McCall et al., 2014; Croisier et al., 2008; Fousekis et al., 2010). Therefore, it is of paramount importance that practitioners accurately monitor and test lower limb strength, power and asymmetry and have the knowledge to interpret the findings in relation to soccer performance and potential injury risk. To ensure appropriate testing takes place, a testing tool must be reliable (Hopkins, 2000), practically utilisable (Mendez-Villanueva and Buchheit 2013) and practically applicable to soccer (Cometti et al., 2001). Additionally, to ensure optimal analysis of testing data, a testing tool must have elite/peer group normative values to compare against and correlation of results with injury risk. Whilst current testing protocols exist within soccer, such as isokinetic dynamometry and jump testing, limitations exist regarding their lack of applicability to soccer movements for the former (Cometti et al., 2001) and lack of ability to safely test at high load in the latter (Risberg et al., 1995). Therefore, alternative testing protocols are needed.

Keiser® are a company that design gym equipment using variable pneumatic air-based resistance. Their equipment varies the resistance applied over the range of motion to maintain a consistent force output throughout each repetition. Through a combination of force produced and velocity of movement, power output is calculated for each repetition. The Keiser® Air420 seated leg press replicates a standard seated leg press with left and right footplates that move independently of each other, therefore providing comprehensive single leg force, velocity and power output and left-right leg bilateral power asymmetries during a seated double leg press. Due to the machine using off loaded movements with feedback data that is applicable to soccer, the

Keiser Air420 is extensively used as a power training and testing tool in elite soccer. However, no research has been completed utilising an elite soccer population.

Therefore, the current thesis aims to:

- Investigate the applicability of the Keiser Air420 seated leg press as a valid lower limb strength and power testing device in the applied soccer environment.
- Provide insights into lower limb strength, power and asymmetry characteristics of elite soccer players using the Keiser Air420.

In an attempt to fulfil these aims, the current thesis will:

- 1) Assess the reliability of elite soccer player performance on the Keiser Air420 through a repeated test-retest protocol.
- 2) Establish the age group and playing position dependent typical characteristic lower limb strength, power and asymmetry profiles for elite soccer players using the Keiser Air420.
- 3) Establish age group dependent variation in strength, power and asymmetry over a season in elite soccer players using the Keiser Air420.
- 4) Investigate the sensitivity to change of lower limb strength, power and asymmetry of elite soccer players assessed using the Keiser Air420 through testing around a competitive soccer match.
- 5) Assess the capability of the Keiser Air420 as a screening tool for injury risk through investigation into the association between pre-season lower limb strength, power and asymmetry and subsequent season-long injury incidence and injury burden of elite soccer players.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

2.1.1 Characteristics of elite soccer

Soccer is one of the most played sports in the world (Hoff and Helgerud 2004) and requires both a high degree of physical conditioning and proficient technical and tactical skill (Arnason et al., 2004). It is characterised as an unpredictable, intermittent high-intensity exercise in which 80-90% of movements can be characterised as low-moderate intensity with 10-20% of performance consisting of short bouts of very intense activity (Bangsbo, 1994; Stølen et al., 2005). Although heavily dependent on playing position, players can accumulate between 9-14 km total distance during a match, of which ~10% or 1-3 km is accumulated at a high intensity (>19.8 km/h) (Mallo et al., 2015; Barnes et al., 2014; Bradley et al., 2010) and around 2% (200-300 m) whilst sprinting (>25.2 km/h) (Ingebrigtsen et al., 2015). Due to the intermittent nature of the sport, discrete energy dense movement changes such as accelerations, decelerations and changes of direction are frequent with an estimated 1000 accelerations and 900 decelerations in total across a match (Akenhead, et al., 2013) making up 18% of total distance covered. Whilst running is the predominant activity, repeated explosive anaerobic efforts such as jumps, striking and tackling (Cometti et al., 2001), which occur on average every 30 seconds (Reilly, Bangsbo and Franks, 2000), also induce significant physiological stress (Dalen et al., 2016) as well as contributing towards the most crucial moments of the game (Comfort et al., 2014). Therefore, to play at an elite level, players need to possess good aerobic fitness, repeated sprint ability (Chaouachi et al., 2010) and anaerobic power (Sheppard and Young, 2006) to successfully complete and maintain explosive movements over a 90-minute match (Mohr, Krstrup and Bangsbo, 2005).

2.1.2 Lower limb strength and power in soccer

Maximal strength is defined as the highest force that can be performed during one maximum voluntary contraction and power output is defined as the ability of the neuromuscular system to produce the greatest amount of work in a given time period (Taber et al., 2016). Therefore, power output is in part dependent on maximal strength capacity and, assuming velocity is not compromised, any increases in maximal

strength will result in an increased force production and subsequent higher power output (Stone et al., 2003; Hoff and Helgerud, 2004; Taber et al., 2016). The successful physical execution of the high intensity, explosive actions in soccer have been found to be dependent to a large degree on the maximal strength and anaerobic power of the lower limbs (Cometti et al., 2001; Reilly et al., 2000). Indeed, positive correlations between maximal strength (Bangsbo, 1994; Schmidtbleicher, 1992; Hoff and Helgerud, 2004; Hoff et al., 2002; Wisloff et al., 2004; Requena et al., 2009) and power output (Newton et al., 2006; Requena et al., 2009; Lopez-Segovia et al., 2011) with physical performance measures of sprint ability and jump height have repeatedly been seen in soccer players, highlighting the importance of their role for optimal performance in soccer.

Lower limb strength and power has also been shown as important in preventing injury in soccer players (Orchard et al., 1997; Croisier et al., 2005; Henderson et al., 2010; van Beijsterveldt et al., 2013) with high levels of lower limb maximal strength and power associated with a lower risk of injury in soccer players (Grace, 1985; Fleck and Falkel, 1986; Bangsbo, 1994). Additionally, lower limb bilateral asymmetries in strength and power between left and right legs have been shown to increase the risk of injury in soccer players with the weaker leg found to be more susceptible to injury (Croisier et al., 2008; Tournay-Chollet et al., 2000).

Therefore, in applied environments, regular lower limb strength and power testing and monitoring is needed to better inform practitioners with regards to the physical performance and injury risk potential of the soccer players they work with. However, to elicit the correct interpretations, it is paramount that appropriate and accurate testing protocols are chosen.

2.1.3 Lower limb strength and power testing protocols in soccer

Numerous test protocols are used to assess and monitor leg strength and power of soccer players, including double leg jumps (Nuzzo et al., 2011), squat lifts (Bosco et al., 1995), seated leg press (Bassey and Short, 1990), single leg hops (Augustsson et al., 2006) and isokinetic dynamometry (Abernethy et al., 1995).

The choice of test used for assessment is normally decided by cost, availability of equipment, applicability to the question that needs answering, and depth of analysis

required. Whilst all assessment protocols mentioned above provide feedback on lower limb strength, power and bilateral asymmetry in some form, each test differs in its skill difficulty, applicability to sporting movements, and ability to isolate individual limbs or muscle groups. Therefore, every testing protocol has its own strengths and limitations that need to be considered when choosing how to evaluate lower limb strength, power and asymmetry.

Single and double leg jumping are actions that are frequently undertaken during soccer performance, and the ability to perform these actions successfully is largely determined by lower limb strength and power. Therefore, single and double leg jump testing can be considered the most practically applicable test of lower limb strength, power and bilateral asymmetry in soccer. Indeed, vertical jump performance has been found to correlate highly with sprint performance (Wisloff et al., 2004; Comfort et al., 2014), whilst horizontal jump performance has been found to correlate well with the ability to change direction at speed (Yanci et al., 2014). Therefore, jump testing can be considered an excellent marker of physical performance in soccer. However, despite the high practical applications, the need to tolerate load-bearing limits the application of maximal jumping with injured players, whilst the influence of movement technique on performance outcome (Bobbert et al., 1986) and inability to isolate single muscle groups limits the use of jump testing as a measurement of lower limb strength and power.

Double leg 1RM squat testing has also been used to evaluate lower limb strength, power and asymmetry. It has been found to have moderate-strong correlations with functional field-based testing with strong positive correlations found between 1RM squat values and both jump (Newton et al., 2006; Blackburn and Morrissey, 1998; Ashley and Weiss, 1994) and sprint performance (Blazevich and Jenkins, 1998). In addition to this, Newton et al., (2006) also found good correlations in force plate assessed bilateral asymmetry found through 1RM squat testing and vertical jump testing, suggesting that 1RM squat testing is a practically applicable lower limb strength, power and bilateral asymmetry testing protocol. However, 1RM squat testing suffers similar limitations to jump testing as a detailed measure of strength and power in soccer, whilst also requiring players to tolerate additional external load bearing in order to obtain results.

At the other end of the testing spectrum, isokinetic dynamometry testing is also used to evaluate lower limb strength and power in soccer. It involves isolating a single muscle group and movement (e.g. knee flexion) and applying continual force at a velocity that is pre-determined over a set range of motion (Baltzopoulos and Brodie, 1989). Whilst it is considered the gold standard for obtaining detailed information on single muscle actions, it requires expensive equipment and training to use and it has been met by criticism that results lack applicability to sport due to the single joint, controlled nature of movement tested (Mayer et al., 2003; Bolgla and Keskula, 1997; Greenberger and Paterno, 1995; Mognoni et al., 1994) and the unnaturally slow velocity of movement (Ashley and Weiss, 1994; Cometti et al., 2001). As a result, research conflicts when comparing isokinetic testing with functional performance tests. Positive results have been found when comparing isokinetic dynamometry testing against more functional isokinetic movements (Negrete and Brophy, 2000; Blazeovich and Jenkins, 1998) with significant correlations found between isokinetic leg press, concentric isokinetic single leg squat and isokinetic leg extension in collegiate students (Negrete and Brophy, 2000). However, the literature conflicts when comparing isokinetic dynamometry testing and double leg jumping, with some studies establishing strong correlations (Newton et al., 2006; Bosco et al., 1983; Genuario and Dolgener, 1980) whilst numerous other studies have found no significant correlations (Anderson et al., 1991; Osterberg et al., 1998). Whilst it appears that correlations between isokinetic dynamometry and jump measurements are stronger when tests are completed at a higher velocity and over more than one joint (Tsiokanos et al., 2002; Iossifidou et al., 2005; Wiklander and Lysholm, 1987), large variation in testing protocols used across the literature means that accurate comparison between studies is difficult and no consensus has been found. Similar conflicting results have been found with single leg hop testing and isokinetic dynamometry, with both positive strong correlations (Negrete and Brophy, 2000; English et al., 2006; Wilk et al., 1994) and moderate-to-low correlations (Greenberger and Paterno, 1995; Osterberg et al., 1998; Pincivero et al., 1997; Barber et al., 1990) found within the literature. When assessing for bilateral asymmetry, despite different testing protocols conferring in the detection of asymmetries across studies (Osterberg et al., 1998), magnitudes established through isokinetic dynamometry testing have not correlated well with asymmetry values evaluated through 1RM and jump testing (Newton et al., 2006; Jones and Bampouras, 2010) or functional field tests (Osterberg

et al., 1998). All of the conflicting literature has led many to believe that isokinetic testing may not be a practically applicable protocol to quantify functional lower limb strength, power and bilateral asymmetry (Greenberger and Paterno, 1995).

It appears that as lower limb strength and power assessment protocols become more closed-chain in nature (multiple joint movements with co-contraction of muscle groups), correlations with functional field tests increase and therefore open-chain testing protocols (single joint movements with isolation of single muscle groups) such as isokinetic dynamometry may be insufficient in assessing the functional performance of the lower limb in soccer players. However, it can also be said that closed-chain strength and power assessment methods may not provide assessment at the degree of detail needed in elite soccer and require participants to load bear to at least bodyweight, which may be inappropriate for compromised individuals. Therefore, to date, no single test has been established that uses controlled offloaded movements applicable to the sporting environment, whilst providing detailed and comprehensive feedback to adequately establish or monitor leg strength and power in as much detail as is needed in elite sport. This thesis aims to investigate whether the Keiser Air420 seated leg press may satisfy these criteria.

Despite the limitations of the lower limb testing protocols mentioned, they are widely used within the literature and applied environment. Therefore their reliability of measurement and normative values in soccer players are discussed below.

2.2 Reliability of leg strength and power testing protocols in soccer

2.2.1 Introduction

For any testing results to be considered valid, the testing protocol and assessment tool used firstly need to be considered reliable. Whilst a well-constructed study design implemented by competent investigators can attenuate the majority of potential errors in a testing protocol, variability in results due to error from mechanical variation of a measurement tool and individual biological variation generally cannot be changed (Atkinson and Nevill, 1998). Therefore this variability needs to be quantified to establish whether a change in results can be confidently attributed to a real change rather than due to potential irregularities in testing equipment (Hopkins, 2000). The

reliability of established leg strength and power assessment protocols has been reported extensively in the literature.

2.2.2 Reliability of lower limb strength and power protocols in soccer players

Double leg jumps in various forms have repeatedly been shown as a very reliable protocol for leg strength and power measurement. Un-resisted and resisted countermovement jumps (Nuzzo et al., 2011; Vitasalo, 1988; Young et al., 1995), depth jumps (Ashley and Weiss, 1994), squat jumps (Ortega et al., 2008) and broad jumps (Wiklander and Lysholm, 1987; Ortega et al., 2008) have all been assessed for reliability in the literature with coefficients of variations (CV) ranging between 1.8%-6% dependent on the test, with all studies suggesting that double leg jumps show 'good' to 'excellent' test-retest reliability.

Double leg strength and power has also been measured for reliability through seated leg press using a dynamometer-based leg press machine, with reliability studies establishing CV values < 6.5% and good to excellent reliability (Bampouras et al., 2014; Bassey and Short, 1990; Avis et al., 1985). Similarly, the pneumatic resistance based Keiser Air420 seated leg press was found to have intraclass correlation coefficient (ICC) values of 0.99 and a non-statistically significant increase of 1.1% in max resistance attained between 2 consecutive trials (LeBrasseur et al., 2008), suggesting 'excellent test-rest reliability'.

Since the vast majority of movements in sport like running, cutting and kicking utilise single leg loading (Williams, 1985; Fousekis et al., 2010; Reilly, 2003), it is generally considered that measurements for the left and right legs taken in isolation may be more applicable. Single leg horizontal hop for distance (Augustsson et al., 2006; Ageberg et al., 1998; Greenberger and Paterno, 1994; Bandy et al., 1994), single leg vertical hop (Manske et al., 2003) and triple hop for distance (Ross et al., 2002; Munro and Herrington, 2011) have all been shown to have 'excellent' reliability with ICC > 0.92 with no significant differences between tests. However, some studies have found large coefficient of variation values for non-dominant leg jumps (Risberg et al., 1995) with researchers suggesting that un-experienced movement technique may significantly influence results (Bolglia and Keskula, 1997; Booher et al., 1993). These findings highlight the need for extensive familiarisation to single leg movements to remove any potential learning effect.

Isokinetic dynamometry testing has also been extensively evaluated for its reliability across various different individual muscle groups working both eccentrically and concentrically across a range of velocities (Gleeson and Mercer, 1992; Pincivero et al., 1997; Madsen, 1996; Li et al., 1996; Tredinnick and Duncan, 1988). Whilst some studies have suggested that contractions at slower speeds may be more reliable than quicker speeds (Abernethy et al., 1995; Hopkins et al., 2001), that concentric muscle contractions may be more reliable than eccentric contractions (Snow and Blacklin, 1992), and that joint movements through extension are more reliable than through flexion (Hopkins et al., 2001), the vast majority of the literature in the area showing isokinetic dynamometry to have good test-retest reliability for isolated muscle actions (Abernethy et al., 1995).

2.2.3 Reliability of bilateral asymmetry measurements in soccer players

The reliability of a variable that is a calculation using another variable, such as bilateral asymmetry, will be dependent on the reliability of the original variables. Therefore, to ensure that reliability holds after calculations have been made, reliability of the original values need to be strong.

A small number of studies have looked into bilateral leg symmetry obtained through a range of single leg hop measurements such as single leg vertical hop, single and horizontal triple hop, 6 m timed hop and combined test values with all studies finding ‘high’ test-retest reliability ($ICC > 0.81$) (Hooper et al., 2002; Reid et al., 2007), suggesting that limb asymmetry scores from various single leg jumps hold similar reliability to that found comparing absolute values.

In contrast, the reliability of leg strength and power asymmetries calculated from single leg measurement from isokinetic dynamometry has shown more conflicting results with studies by Hsu et al., (2002) and Impellizzeri et al., (2008) showing lower reliability ($ICC < 0.81$, standard error of the mean (SEM): 3.2-8.7%) when looking into the test-retest left-right differences in peak torque and average work despite finding high and ‘excellent’ reliability for raw single leg values. Therefore, although very reliable in reproducing similar results from single leg isolated movements, isokinetic dynamometry may not provide reliable results in relation to bilateral leg asymmetry scores.

In comparison to the research above and in an attempt to validate the testing protocol in soccer players in a similar way to alternative testing modalities, Chapter 4 in the current thesis will establish the repeated test-retest reliability of double leg maximal strength, single leg power output and bilateral asymmetry of elite soccer players using the Keiser Air420 seated leg press

2.3 Typical characteristic leg strength and power values in soccer players

2.3.1 Introduction

In the applied environment, establishing typical characteristic values for elite soccer players using a particular testing protocol is essential, as it establishes a barometer for where individuals are in comparison to their population leading to better evaluation of an individual's test results for both coaches and trainers (Magine et al., 1990). Subsequently, the knowledge of typical performance of their peers and senior professionals provides motivation and goal setting for younger players as they progress.

2.3.2 Typical characteristic leg strength and power values in soccer players

Many studies have looked to establish normative data values related to lower limb strength and power in elite soccer players, and most commonly, this has been done using jump profiles (see Table 2.1). As an overview, many studies have found elite soccer players to attain vertical jump height values of anywhere between 40-60 cm (Hoff and Helgerud, 2004; Strudwick et al., 2002; Mujika et al., 2009; Thomas and Reilly, 1979; Wisloff et al., 1998; Wisloff et al., 2004). When looking at more restricted jumping movements, studies have found slightly lower average values in elite soccer players with a restricted countermovement jumps (vertical jump without the use of arms) and squat jumps (non-countermovement jump with individuals holding a squat position with a 90 degree knee angle for 2 seconds before jumping without the use of arms) finding typical values between 39-45 cm and 37-44 cm, respectively (Arnason et al., 2004; Boone et al., 2012; Castagna and Castellini, 2013; Cometti et al., 2001; Mujika et al., 2009; Sporis et al., 2009). Whilst some studies have found significant correlations between a team mean double leg countermovement jump height and their league ranking (Arnason et al., 2004; Cometti et al., 2001), others have failed to do so (Castagna and Castellini, 2013;

Mujika et al., 2009; Thomas and Reilly, 1979). Additionally, despite continual changes in training and match load across a season, Thomas and Reilly (1979) found no significant differences between jump performance at any time point across a season suggesting pre-season jump testing results are reflective of jump height across a season. However this area has not been extensively researched.

Isokinetic dynamometry has also been used to establish typical characteristic lower limb strength and power values in soccer players over a range of velocities and muscle contractions (See Table 2.2), although due to widely varying protocols, collating and concisely summarising typical characteristic values is difficult. As a general overview, soccer players show increasing peak torque values as velocity decreases for all muscle contractions (Daneshjoo et al., 2013; Amato et al., 2001; Oberg et al., 1984; Zakas, 2006). Higher peak torque values are found through concentric hamstring action (concentric knee flexion-CKF) in comparison concentric quadriceps action at all velocities (concentric knee extension-CKE) (Gur et al., 1999; Fousekis et al., 2010; Rochcongar et al., 1988) and through eccentric hamstring action (eccentric knee extension- EKE) in comparison to eccentric quadriceps action (eccentric knee flexion- EKF) at all velocities (Cometti et al., 2001; Fousekis et al., 2010; Tourney-Chollet et al., 2000). Higher peak torque values are found in eccentric hamstring action (EKE) over concentric hamstring action (CKF) at all velocities (Cometti et al., 2001; Fousekis et al., 2010; Gur et al., 1999). However, when looking at quadriceps peak torque values, higher values are found in concentric muscle action (CKE) at low (30 °/s and 60 °/s) velocities but in eccentric muscle action (EKF) at high (180 °/s and 300 °/s) velocities (Gur et al., 1999; Fousekis et al., 2010). Studies have found positive correlations between peak torque values and football ability levels (Oberg et al., 1986; Togari et al., 1988; Gil et al., 2010), particularly in eccentric hamstring contractions (Cometti et al., 2001), with increases attributed to increasing intensity of movement in both training and matches as ability level increases (Oberg et al., 1986).

Isokinetic dynamometry has been used to establish normative values for strength asymmetries between two legs, and whilst many studies have found no significant differences between legs using isokinetic dynamometry (Magine et al., 1990; Rochcongar et al., 1988; Daneshjoo et al., 2013; Zakas et al., 2006; Capranica et al.,

1992; Rahnema et al., 2005), others have found significant differences in quadriceps and hamstring peak torque between dominant and non-dominant legs over a range of velocities (McLean and Tumilty, 1993; Tourney-Chollet et al., 2000; Kellis et al., 2001; Gur et al., 1999). In particular, Kellis et al., (2001) found significantly higher peak values for the dominant (preferred kicking) leg and more specifically, studies have found significantly higher values in concentric and eccentric hamstring peak torque at high velocities in the dominant leg (Tourney-Chollet et al., 2000; Gur et al., 1999) amongst soccer players. Findings have been attributed to increased quantity of repeated kicking action with the dominant leg in soccer practice (Gur et al., 1999).

Whilst significant differences between limbs in soccer players have not been established across the literature, asymmetries are consistently seen in studies. Despite some studies finding larger strength and power values in non-dominant legs of elite soccer players (Rahnema et al., 2005; Daneshjoo et al., 2013), potentially through supporting bodyweight in the stance phase of kicking, the majority of studies suggest that the dominant leg is consistently stronger than the non-dominant leg with asymmetries ranging between 2-10% (Arden et al., 2016; Fousekis et al., 2010; Tourney-Chollet et al., 2000; Brito et al., 2010; Kellis et al., 2001; Leatt et al., 1987; Menzel et al., 2013). Looking into this in greater detail, Forbes et al. (2009) found no effect of age on leg asymmetries, however other studies have found lower asymmetries in elite players with a longer training age (Fousekis et al., 2010; Gur et al., 1999)

Interestingly, although left-right leg strength asymmetries established through various jumping movements have been extensively researched within the literature with athletes (Newton et al., 2006; Clark, 2001; Noyes et al., 1991), minimal research has been completed with soccer players. Magine et al. (1990) found a non-significant 1% difference between legs in a hop for distance and a timed hop, whilst double leg countermovement jumps have established dominant leg preference in max force of between 5.5-6.2% (Impellizzeri et al., 2007; Menzel et al., 2013). However, without a depth of studies to support these findings, drawing strong conclusions of normative leg asymmetries in soccer players through double or single leg jumps would be inaccurate. Additionally, despite the fact that intense training or accumulated fatigue over a season may have an impact on bilateral strength and power, there is no

research assessing whether different periods within a season have an effect on the magnitude of bilateral asymmetry of soccer players.

To add to this area of research, Chapter 5 will investigate the typical strength, power and bilateral asymmetry normative values for a soccer player assessed through seated leg press at a single time point and also at four time points across a season to see whether any variation is evident.

2.3.3 Influence of playing position

Typical characteristic lower limb strength, power and asymmetry values have also been established for different playing positions in soccer. Although Davis et al. (1992) found no significant differences between jump heights in different playing positions, across the literature, it has been found that midfielders consistently produce lower jumps and peak torque values than goalkeepers, defenders and strikers (Boone et al., 2012; Raven, 1976; Wisloff et al., 1998; Bangsbo, 1994; Arnason et al., 2004; Tourney Chollet et al., 2000; Oberg et al., 1984), whilst goalkeepers have also been seen to produce significantly higher peak torque values than other positions (Arnason et al., 2004; Oberg et al., 1984). It has been suggested that these higher values produced by goalkeepers is a strong reflection on the unique physical position specific demands and therefore repeated daily practices such as repeated jumping and diving undertaken (Oberg et al., 1984; Arnason et al., 2004). However, Reilly et al. (2000) suggest that strength differences between playing positions are, in fact, due to selection of a particular type of player for a playing position rather than development of strength as a result of playing in that position. Whilst both may be true, for appropriate individualised programming, identification of positional differences is important.

Tourney-Chollet et al. (2000) looked into the effect of playing position on bilateral asymmetry and whilst finding small differences between positions with players showing a mild strength preference towards their dominant leg, midfielders showed higher quadriceps strength across all velocities in their non-dominant leg. The authors attributed this to the unique requirement to perform many strength-based duels and frequent changes of direction in comparison to other positions. The authors also suggest that strength preferences between dominant and non-dominant legs may not

be universal amongst soccer players and in fact dependent on their playing position and/or style, however this has not been further corroborated within the research.

2.3.4 Influence of playing age

Similar to studies on non-elite athlete populations, research has found increases in strength with increasing age in elite soccer players (Gur et al., 1999; Forbes et al., 2009; Buchheit and Mendex-Villnueva, 2013). Indeed, improvements in strength have been found in elite youth soccer players between 10-18 years using isokinetic dynamometry also (Forbes et al., 2009; Kellis et al., 2001) with Amato et al. (2001) finding significantly higher peak torque values in 20 year old elite soccer players in comparison to those 5 years younger. Similarly, Buchheit and Mendez-Villanueva (2013) found linear decreases in sprint time and increases in CMJ and maximal running speed in relation to age in elite youth soccer players ranging between 13-17 years old.

Whilst this is somewhat to be expected through the physiological changes of maturation, research has also considered the impact of age on strength and power values in adult elite soccer populations. Gur et al. (1999) studied 2 groups of elite soccer players, adults (> 21 years old) and young players (< 21 years old) and found eccentric and concentric knee torque values were significantly higher in adult players. These differences were, however, only seen in the players' dominant kicking leg, with no differences between the groups in the non-dominant leg leading the authors to suggest the differences found were a product of a higher training age rather than simply age alone. To support this, Fousekis et al. (2010) found that players with an intermediate or long training age (8+ years training history) had higher strength values than those with a low training age (< 7 years training history). Interestingly, in the same study, no differences were found between intermediate (8-10 years history) and long training age (10+ years) players, suggesting there may be a plateau in strength gains made through prolonged exposure to soccer training or an offset in any further improvements with strength decline with age. To support this, Manson et al. (2014) found that bodyweight-relative hip and knee peak torque values were higher in U20 female elite soccer players in comparison to U17 players but that there were no significant differences between U20 females and the senior squad. Similarly, Rochanger et al. (1988) compared isokinetic peak torque values of adult elite soccer

players with those from different age ranges (U18 years old; U16 years old; U14 years old) and although values significantly increased through the age groups, when corrected for weight, no differences were seen between the adults and U18 soccer players or between U14 and U16 age groups, leading authors to suggest that significant strength changes occur around 16 years old. Interestingly, when looking into more functional strength performance measures, both Mujika et al. (2009) and Castagna and Castellini (2013) found no differences between senior and junior international elite male soccer players in jump scores or sprint times. Therefore, although the research suggests that strength gains are clearly seen through adolescent years, the strength and power of soccer players may plateau after pubescent years. This appears to be particularly seen in strength and power movements that are more functional in nature, however the nature and timing of this is still unknown and warrants further research.

To further both of the concepts mentioned above, Chapter 5 of the thesis will also investigate whether there are any differences in lower limb strength, power and bilateral asymmetry in elite soccer players across playing position as well as across three training age/experience groups ranging between 16-20 years old.

Table 2.1: Overview of soccer specific double leg jump results across the literature

Study	Demographic	Tests completed	Findings
Mujika et al. (2009)	34 professional male soccer players	CMJ CMJ+A	CMJ: 43.7±2.2cm CMJ+A: 50.1±4.2cm
Thomas and Reilly (1979)	31 male soccer players	CMJ+A SBJ	CMJ+A: 54±6.3 cm SBJ: 225±11.6 cm
Wisloff et al. (2004)	17 professional male soccer players	CMJ+A	CMJ+A: 56.4±4.0 cm
Wisloff et al. (1998)	29 professional male soccer players	CMJ+A	CMJ+A: 54.9±5.3 cm
Arnason et al. (2004)	214 professional male soccer players	CMJ SJ	CMJ: 39.2±5.0 cm SJ: 37.6±4.8 cm
Boone et al. (2012)	289 professional soccer players	CMJ SJ	CMJ: 43.1±4.9 cm SJ: 40.7±4.6 cm
Castagna and Castellini (2013)	56 professional soccer players	CMJ SJ	CMJ: 40.5±4.4 cm SJ: 37.6±4.4 cm
Cometti et al. (2001)	29 professional soccer players	CMJ SJ	CMJ: 41.6±4.2 cm SJ: 38.5±3.8 cm
Sporis et al. (2009)	270 elite soccer players	CMJ SJ	CMJ: 45.1±1.7 cm SJ: 44.1±1.3 cm
Silvestre et al. (2006)	25 collegiate soccer players	CMJ+A	CMJ+A: 61.9±7.1 cm
Raven et al. (1976)	18 professional soccer players	CMJ+A	CMJ+A: 52.8±2.5 cm
Caldwell and Peter (2009)	13 semi-professional soccer players	CMJ+A	CMJ+A: 57±1.9 cm

CMJ: Countermovement jump without arms, CMJ+A: Countermovement jump with arms,
SBJ: Standing broad jump, SJ: Squat Jump

Table 2.2: Overview of soccer specific isokinetic dynamometry results across the literature

Study	Demographic	Angles and Velocities Tested	Peak Torque (PT) Main Findings (Results Averaged)
Amato et al. (2001)	38 soccer players	CKF @ 60 and 180 °.s ⁻¹ CKE @ 60 and 180 °.s ⁻¹	CKF: 60 °.s ⁻¹ -148 Nm, 180 °.s ⁻¹ - 114 Nm CKE: 60 °.s ⁻¹ -205 Nm, 180 °.s ⁻¹ -124 Nm PT higher for older players vs. younger players
Cometti et al. (2001)	95 soccer players (29 elite, 34 sub elite, 32 amateur)	CKF @ 60,120,180, 240, 300 °.s ⁻¹ CKE @ 60,120,180, 240, 300 °.s ⁻¹ EKF @ 60, 120 °.s ⁻¹ EKE @ 60, 120 °.s ⁻¹	Estimated from graphs CKF ranging from 140 Nm (60 °.s ⁻¹) to 95 Nm (300 °.s ⁻¹) CKE ranging from 225 Nm (60 °.s ⁻¹) to 110 Nm (300 °.s ⁻¹) EKF: 60 °.s ⁻¹ -165 Nm, 120 °.s ⁻¹ - 165 Nm EKE: 60 °.s ⁻¹ -265 Nm, 120 °.s ⁻¹ - 285 Nm Elite KF strength higher than amateur across velocities
Daneshjoo et al. (2013)	36 professional soccer players	CKE @ 60, 180, 300 °.s ⁻¹ CKF @ 60, 180, 300 °.s ⁻¹	CKF: 60 °.s ⁻¹ -101 Nm, 180 °.s ⁻¹ - 68 Nm, 300 °.s ⁻¹ - 67 Nm CKE: 60 °.s ⁻¹ -205 Nm, 180 °.s ⁻¹ - 129 Nm, 300 °.s ⁻¹ - 94 Nm
Fousekis et al. (2010)	115 professional soccer players	CKE @ 60, 180, 300 °.s ⁻¹ CKF @ 60, 180, 300 °.s ⁻¹ EKF @ 60, 180 °.s ⁻¹ EKE @ 60, 180 °.s ⁻¹	CKF: 60 °.s ⁻¹ -136 Nm, 180 °.s ⁻¹ - 104 Nm, 300 °.s ⁻¹ - 94 Nm CKE: 60 °.s ⁻¹ -238 Nm, 180 °.s ⁻¹ - 167 Nm, 300 °.s ⁻¹ - 135 Nm EKF: 60 °.s ⁻¹ -192 Nm, 180 °.s ⁻¹ - 187 Nm EKE: 60 °.s ⁻¹ -308 Nm, 180 °.s ⁻¹ - 293 Nm PT increased as professional training age increased
Gur et al. (1999)	25 professional soccer players	CKE @ 30, 180, 240, 300 °.s ⁻¹ CKF @ 30, 180, 240, 300 °.s ⁻¹ EKF @ 30, 180, 240, 300 °.s ⁻¹ EKE @ 30, 180, 240, 300 °.s ⁻¹	CKF ranging from 130 Nm (30 °.s ⁻¹) to 77 Nm (300 °.s ⁻¹) CKE ranging from 232 Nm (30 °.s ⁻¹) to 127 Nm (300 °.s ⁻¹) EKE ranging from 258 Nm (30 °.s ⁻¹) to 252 Nm (300 °.s ⁻¹) EKF ranging from 141 Nm (30 °.s ⁻¹) to 152 Nm (300 °.s ⁻¹) PT increased as chronological age increased
Magine et al. (1990)	83 international level professional soccer players	CKF @ 60 and 450 °.s ⁻¹ CKE @ 60 and 450 °.s ⁻¹	CKF: 60 °.s ⁻¹ -66.5 Nm, 450 °.s ⁻¹ - 48 Nm CKE: 60 °.s ⁻¹ -122 Nm, 450 °.s ⁻¹ -72 Nm
Oberg et al. (1984)	180 elite soccer players	CKE @ 30 and 180 °.s ⁻¹	CKE: 30 °.s ⁻¹ -249 Nm, 180 °.s ⁻¹ -143 Nm PT higher in goalkeepers and defenders vs. strikers
Rahnama et al. (2005)	41 elite and sub elite soccer players	CKE @ 60, 120 and 300 °.s ⁻¹ CKF @ 60, 120 and 300 °.s ⁻¹ EKE @ 120 °.s ⁻¹ EKF @ 120 °.s ⁻¹	Estimated from graphs CKF: 60 °.s ⁻¹ -140Nm, 120 °.s ⁻¹ - 125Nm, 300 °.s ⁻¹ - 110Nm CKE: 60 °.s ⁻¹ -250Nm, 120 °.s ⁻¹ - 210Nm, 300 °.s ⁻¹ - 155Nm EKE: 120 °.s ⁻¹ - 300Nm EKF: 120 °.s ⁻¹ - 165 Nm

Rochcongar et al. (1988)	24 professional soccer players	CKE @ 30 and 180 °.s ⁻¹ CKF @ 30 and 180 °.s ⁻¹	CKE: 30 °.s ⁻¹ -214 Nm, 180 °.s ⁻¹ -146 Nm CKE: 30 °.s ⁻¹ -130 Nm, 180 °.s ⁻¹ -111 Nm PT increased with chronological age
Tourney-Chollet et al. (2005)	21 amateur soccer players	CKE @ 60, 120 and 240 °.s ⁻¹ CKF @ 60, 120 and 240 °.s ⁻¹ EKF @ 60 and 120 °.s ⁻¹ EKE @ 60 and 120 °.s ⁻¹	CKF: 60 °.s ⁻¹ -99 Nm, 120 °.s ⁻¹ - 86 Nm, 240 °.s ⁻¹ - 68 Nm CKE: 60 °.s ⁻¹ -153 Nm, 120 °.s ⁻¹ - 134 Nm, 240 °.s ⁻¹ - 107 Nm EKF: 60 °.s ⁻¹ - 121 Nm, 120 °.s ⁻¹ - 114 Nm EKE: 60 °.s ⁻¹ - 198 Nm, 120 °.s ⁻¹ - 190 Nm Forwards showed higher CKF than Midfielders with no other differences.
Zakas (2006)	42 professional soccer players	CKE @ 12, 60, 180, 300 °.s ⁻¹ CKF @ 12, 60, 180, 300 °.s ⁻¹	CKF ranging from 144Nm (12°.s ⁻¹) to 60Nm (300°.s ⁻¹) CKE ranging from 267 Nm (12 °.s ⁻¹) to 113 Nm (300 °.s ⁻¹)

CKF: Concentric Knee Flexion, CKE: Concentric Knee Extension, EKE: Eccentric Knee Extension, EKF: Eccentric Knee Flexion

2.4 Effects of fatigue on lower limb strength and power

2.4.1 Introduction

Fatigue has been defined as the ‘failure to maintain the required or expected power output’ (Edwards, 1983) and is identified as ‘a reversible decline in a muscle’s force generating capacity’ (Spendiff et al., 2002). It is generally considered that the magnitude and rate of development of fatigue is dependent on the duration and intensity of activity as well as the type of muscle contraction performed (Thorlund et al., 2009).

As physical success in an intermittent high intensity sport such as soccer is largely dependent on the ability to maintain or attenuate the decrease in the muscles’ peak force generating capacity, understanding the causes of match play-induced fatigue and the subsequent impact on performance is important.

2.4.2 Fatigue and physical performance in soccer

It has been long reported that a decline in physical performance, qualified as fatigue, can be observed in soccer matches with Reilly and Thomas (1976) commenting ‘in top class soccer, a fatigue effect is noticeable in the second half as reflected by a drop in work rate’. This was originally supported with many studies establishing that there is a decrease in total distance covered in the second half of matches in comparison to the first (Van Gool et al., 1988; Bangsbo et al., 1991) and more specifically a decrease in high intensity and sprint distance covered in the second half of matches and particularly in the final 15 minutes of a match (Rampinini et al., 2009; Bradley et al., 2009; Krusturup et al., 2006; Mohr et al., 2005). Bradley et al. (2009) found that mean recovery time between high intensity running bouts drop towards the end of matches with 28% and 17% longer recovery between high intensity and sprint bouts respectively in the final 15 minutes in comparison to the first 15 minutes. To add greater depth to the findings, Mohr et al. (2003) found that substitute players that enter the game in the second half complete 63% more sprint distance and 25% more high intensity distance during that period than players who have completed the full game, highlighting that decreases in workload were due to fatigue rather than a natural variation in the intensity of a match. It has, however, been suggested that these decreases in second half load are only evident if individuals complete more than their

‘normal’ physical output in the first half of matches, with Rampinini et al. (2007) finding that players who completed less than their normal output, had no decrement in physical performance across a full match.

Rather than simply looking at decline in physical performance over a match, it has been suggested that ‘temporary fatigue’ following a period of increased high intensity actions may be a more relevant fatigue measurement during matches. Krustup et al. (2006) found that the 3rd, 4th and 5th sprints carried out after a period of intense play were reduced compared to sprint performance pre-match, whilst sprint performance at half time was not, suggesting that temporary fatigue in soccer may have a greater impact on physical performance than accumulated fatigue. Similarly, Mohr et al. (2003) found a significant decline in high intensity running in a five-minute period following the period covering the most high intensity running, whilst Bradley et al. (2010) found a decrease in high intensity running by almost 50% in the five minutes following the most intense five minute period of the game, which was also 6-8% lower than the average five minute period across that match. It has also been suggested that a decrease in physical performance may be correlated with a decrease in technical performance. Indeed, Rampinini et al. (2009) found that players who showed the larger decline in physical performance across a match also had a greater decline in number of successful short passes played between the two halves re-emphasising the importance of physical fitness for successful overall performance in soccer.

Changes in physical performance over a longer period, such as a whole season or a period of congested fixtures, has also been investigated to see whether accumulated fatigue may occur. However, there is no decrease in physical performance in matches through periods of congested fixtures (Dellal et al., 2015; Carling et al., 2012) or in comparison between teams that had one match vs. two matches per week (Dupont et al., 2010; Bengtsson et al., 2013). In fact, Mohr et al. (2003) found an increase in a team’s total distance covered and high intensity running in matches at the end of the season in comparison to any other period within the season. Despite no physical decline evident, it has been suggested that decreases in performance are still seen following condensed periods of match load, with Ekstrand et al. (2004b) establishing that players classified as ‘underperformers’ in a World Cup averaged 12 matches in the 10 weeks preceding the competition whilst ‘over performers’ averaged 9 matches

in the 10 weeks, suggesting that accumulation of match load may have a delayed impairment on technical performance.

As a decrease in physical output is clearly seen within soccer match play, to try and minimise it, it is important to investigate which elements of physical performance may be affected by fatigue.

2.4.3 Impact of fatigue on lower limb performance

It has long been recognised that fatigue-inducing exercise will have a negative effect on lower limb strength and power capacity due to a decrease in ability to recruit muscle fibres to generate force (Bangsbo, 1991), a decrease in energy stores (Beelen and Sargeant, 1991) and an impairment of neuromuscular function (Mercer et al., 1998). In general, it has been clearly shown that high intensity exercise will induce larger decreases in subsequent power output than low intensity exercise (Spendiff et al., 2002) and that multi directional intermittent high intensity exercise induces greater decreases in strength and power in comparison to continuous lower intensity unidirectional exercise. Therefore, it is reasonable to expect that a multi directional intermittent high intensity sport such as soccer is likely to have a negative effect on lower limb performance. Indeed, fatigue induced through soccer simulated activity or soccer match participation has been shown to decrease isokinetic dynamometry peak torque values, sprint ability and jump performance both immediately post and for a prolonged period post exercise (Rahnama et al., 2003; Ali and Williams, 2013; Andersson et al., 2008; Hoffman et al., 2003).

Many studies have highlighted significant decreases in lower limb strength and power through isokinetic dynamometry immediately following a soccer match or replicated soccer specific protocol. In comparison to pre-task values, decrease of between 7-25% for eccentric and concentric knee flexion and extension at various speeds have been found (Andersson et al., 2008; Ascensao et al., 2008; Thorlund et al., 2009; Ali and Williams, 2013; Rahnama et al., 2003; Mercer et al., 2003), with research particularly highlighting increased decrements in eccentric hamstring strength through knee extension (Greig, 2008; Robineau et al., 2012). Robineau et al. (2012) found that during a 90-minute intermittent running protocol, concentric and eccentric hamstring and quadriceps values significantly decreased from baseline values, with the most significant decreases seen in eccentric hamstring strength. Similarly, Greig (2008)

found that eccentric torque of both quadriceps and hamstrings significantly decreased over a 90-minute soccer specific running protocol. To further support this, Greig and Siegler (2009) found that eccentric hamstring strength progressively declined over a 90-minute intermittent sprint running protocol, with the largest decreases seen at the high velocity ($300^{\circ} \cdot s^{-1}$). The authors suggest that decreases seen, in particular in eccentric hamstring strength, may be due to the large number of explosive knee extension dominant efforts that occur during a soccer match. As many of these efforts are involved in actions such as striking the ball, jumping and battling with opponents (Bangsbo, 1994), evaluating lower limb performance following relative soccer specific running protocols may underestimate fatigue and therefore, for accurate results, lower limb testing around competitive soccer match play is optimal. Research has also investigated the prolonged effects of competitive match play on isokinetic testing with Andersson et al. (2008), finding significant reductions in knee extension and flexion values at 5 and 21 hours post-exercise, returning to baseline after 27 and 51 hours respectively. Ascensao et al. (2008) also reported decreased knee flexion and extension values that did not return to baseline until 72 hours post match. Field testing has also been undertaken around fatiguing soccer specific protocols and match play to see their effects on lower limb strength, power and performance.

To date, research is conflicting regarding the performance of countermovement, squat, and drop jump scores following soccer specific protocols with some studies finding significant differences immediately post soccer specific treadmill running (Oliver et al., 2008; Robineau et al., 2013) and soccer match play (Andersson et al., 2008) but an equal number that reported no significant decrease immediately post (Krustrup et al., 2010; Hoffman et al., 2003; Thorlund et al., 2009). The research, however, does seem to suggest that significant decreases in jump performance are seen 24 hours post-match of anywhere between 4-10% (Fatouros et al., 2010; Andersson et al., 2008; Hoffman et al., 2003; Ispirlidis et al., 2008). Sprint testing seems to offer more consistent findings with the majority of the research in the area finding decrements in 20 and 30-m sprint times of between 3-7% immediately post-match (Ascensao et al., 2008; Andersson et al., 2008; Krustrup et al., 2010) and significantly slower sprint performance lasting 24, 48 and 72 hours post-match (Ispirlidis et al., 2008; Fatouros et al., 2010; Ascensao et al., 2008). Similarly, Ispirlidis et al. (2008) found significant decreases in double leg 1RM squat

performance, which lasted until 72 hours post-match. In the only study found to date looking into the effect of fatigue on bilateral asymmetry, Rahnema et al. (2003) found no difference in asymmetry following a soccer specific treadmill protocol, despite finding significant decreases from baseline in absolute strength and power isokinetic values at half time and full-time measurements.

Due to the potential importance of bilateral power asymmetries on injury risk and performance discussed earlier, establishing the effect of fatigue from soccer match play on the magnitude of asymmetry is practically important and warrants further research in the literature. Chapter 6 of the current thesis will aim to do this through investigating the immediate and delayed effect of soccer match play on bilateral asymmetry as well absolute strength and power values.

2.4.4 Impact of fatigue on lower limb injury risk

In addition to the negative impact that match play induced fatigue has on overall physical performance and particularly lower limb strength and power, fatigue induced decrements in performance are also thought to have an impact on injury risk in soccer players. Low levels of lower limb strength and power have been found to increase injury risk (Burkett et al., 1970; Engebretsen et al., 2010) and since fatiguing physical exertion decreases lower limb strength and power (Rahnema et al., 2003; Ali and Williams, 2013; Andersson et al., 2008; Hoffman et al., 2003), it can be clearly hypothesised that decreases in a lower limb strength and power due to fatigue will increase risk of lower limb injury (Rahnema et al., 2003; Mair et al., 1996; Woods et al., 2004). Many studies have supported this by suggesting that fatigue is a primary risk factor for injury in soccer (McCall et al., 2014; Carling et al., 2010; Small et al., 2010).

It has been consistently shown that there is a greater incidence of injury in soccer in the 2nd half of matches than at any other time in training or matches (Hawkins et al., 2001) with a greater than average frequency of injury observed during the final 15 minutes in the first half and final 30 minutes in the second half of matches (Hawkins and Fuller, 1999). Similarly, from a 9 year study with 51 teams, Ekstrand et al. (2011a) found increased injury incidence in matches towards the end of each half and Small et al. (2008) found that 47% of all hamstring injuries, the most common muscle injury in soccer (Hawkins et al., 2001), occur in the final 15 minutes of each half.

Therefore, despite research not directly establishing a link between injury incidence and fatigue induced decreases in strength and power, when timing of injury incidence in soccer matches are compared with the decline in physical performance seen across a match as mentioned in section 2.4.3, intuitive associations can be drawn.

Similarly, Carling et al. (2010) found an increase in high intensity work completed and a decrease in recovery time between actions in the 5 minutes prior to injury in the French 1st Division. When this research is taken alongside Krstrup et al. (2006) who found temporary fatigue in the form of increased sprint times following acute spikes in match play physical activity, it could be suggested that temporary fatigue in soccer match play may be linked with injury incidence as well. Indeed, the increase in injury incidence towards the end of matches may be due to temporary fatigue from an increase in intensity at these time points with Rahnema et al. (2003) finding that there were more actions with ‘moderate injury potential’ in the final 15 minutes of a match than in any other 15-minute period.

When considering fatigue over a longer period, studies have established moderately higher injury incidences at the end of a soccer season suggesting an effect of accumulative fatigue across the season (Hawkins and Fuller 1999; Ekstrand et al., 2011). Bengtsson et al. (2013) also found an increase in injury incidence in teams that had 4 days or less between matches in comparison with teams that had 6 days or more between matches. Finally, in comparison to 29% injury occurrence for all players at the 2002 World Cup, Ekstrand et al. (2004b) found that 60% of players that played more than 1 match per week in the final 10 weeks of a season leading up to a 2002 World Cup subsequently sustained an injury in the tournament

Therefore, despite no studies directly establishing a correlation between acute or accumulated fatigue-induced decreases in lower limb strength and power and injury incidence in soccer, it is clear that connections across studies linking the two can be seen. Due to the negative impact that injury and physical performance decreases have on soccer performance, the effect of acute fatigue from soccer match play on lower limb performance needs to be quantified. Chapter 6 of the thesis aims to further the knowledge in this area by investigating the immediate and 24 hr post-match effects of soccer match play on lower limb strength, power and bilateral asymmetries assessed through the Keiser Air420 seated leg press protocol.

2.5 *Injury incidence in soccer*

2.5.1 *Introduction*

Due to high physical demands on the body and continued exposure to potential hazardous environments, the risk of injury within elite soccer, is relatively high (Waldén, Hagglund and Ekstrand, 2005) with studies finding injury incidence rates between 3.4 and 5.9 per 1000 training hours and 25.9 and 34.8 per 1000 match hours (Hawkins and Fuller, 1999; Ekstrand et al., 2004a; Ekstrand et al., 2011a; Arnason et al., 2004). A professional soccer player can expect, on average, to pick up 2.0 total injuries (Ekstrand et al., 2011a) and 0.6 muscle injuries per season (Ekstrand et al., 2011b) with muscle injury the most common cause of time lost through injury, making up anywhere between 20-41% of all injuries (Ekstrand et al., 2011a; Ekstrand et al., 2011b; Hagglund et al., 2013; Hawkins and Fuller, 1999). Overall, 92% of all muscle injuries sustained by professional soccer players occur in one of four areas: hamstrings, adductors, quadriceps or calf, with the majority (37%) occurring in the hamstrings (Hawkins and Fuller, 1999; Arnason et al., 2004; Walden et al., 2005; Ekstrand et al., 2011b). Quadriceps and adductor muscle injuries have been found to be more common on the preferred kicking leg with no differences between legs for hamstring or calf injuries (Hagglund et al., 2013). Multifactorial models have been developed to help explain injury incidence (Meeuwisse et al., 2007; Windt and Gabbett, 2017) and the risk factors relating to muscle injuries, defined as any attribute or element that affects the likelihood of incurring an injury, have been extensively researched (Hagglund et al., 2013; Opar et al., 2012; Arnason et al., 2004; Ekstrand et al., 2011b). Although certain external risk factors such as opponent behaviour cannot be accounted for, due to the impact that injuries can have, identifying the internal modifiable risk factors for injury within any given sport it is of the utmost importance so that at-risk individuals can be identified and preventative strategies can be implemented. One major modifiable internal risk factor for soft tissue injuries in elite athletes identified is lower limb muscle strength weakness (Orchard et al., 1997; Croisier et al., 2005; Henderson et al., 2010; van Beijsterveldt et al., 2013).

2.5.2 *Lower limb strength and power and injury incidence in soccer*

As mentioned previously, it has been consistently suggested that low absolute muscular strength can be linked with an increase in injury incidence (Burkett et al.,

1970; Knapik et al., 1991; Orchard et al., 1997; Tyler et al., 2001; Croisier et al., 2002) with Agre (1985) suggesting that weakness in the hamstring muscles is the most common factor involved in hamstring strains.

In one of the earliest pieces of correlation research published in the area, Burkett et al. (1970) found significantly lower pre-season isokinetic strength values in American football athletes who subsequently sustained hamstring injuries in comparison to those that did not, with 66% of athletes identified with ‘strength deficiencies’ sustaining a hamstring injury at some point over the season. Similarly, Orchard et al. (1997) found that Australian Rules football players who sustained hamstring injuries across a season had 16% weaker strength values in the preceding pre-season isokinetic testing. Tyler et al. (2001) found ice hockey players that sustained adductor strains had 18% weaker hip adductors in preseason testing. More specifically, results have also been replicated in the soccer population with Engebretsen et al. (2010) establishing that soccer players with clinically determined weak adductor strength had a four times higher groin injury risk than those with adequate strength and Ekstrand and Gillquist (1983) reporting significantly lower isokinetic knee extension peak torque values in players who subsequently sustained non-contact knee injuries in comparison to those who did not sustain an injury. Conversely, research has also established weak relationships between strength values and injury incidence in soccer (Bennell et al., 1998; Ostenberg and Roos, 2000; Soderman et al., 2001; Ekstrand and Gillquist, 1983). Indeed, despite finding lower peak torque values in players who subsequently sustained knee injuries, Ekstrand and Gillquist (1983) did not find any relationship between strength values and subsequent hamstring injury incidence in soccer players. Additionally, pre season isokinetic strength values have been found to have no relationship with subsequent injury incidence in female soccer players across multiple studies (Soderman et al., 2001; Ostenberg and Roos, 2000). Therefore, although there is significant research supporting the relationship between absolute strength and injury risk, conflicting studies highlight the fact that correlation between strength and injury risk may not extend to a cause and effect between the two elements particularly when injury incidence is likely to be a multifactorial issue (Meeuwisse, 1994).

Interventions studies investigating changes in strength and power and injury incidence have established strong relationships with increased strength through sustained

resistance training consistently found to reduce injury incidence in sportsmen (Fleck and Falkel, 1986; Heidt et al., 2000; Askling et al., 2003; Heiser et al., 1984).

Working under the basic principle of resistance training increasing muscular, tendon and ligament strength as well as bone density (Fleck and Falkel, 1986), Heiser et al. (1984) found that American football players that used strength training to increase strength and correct for potential bilateral asymmetries decreased injury risk by 6% in comparison to those that did not. Looking at a soccer specific demographic, Heidt et al. (2000) found a 19% lower injury incidence in female soccer players who completed a seven week resistance training programme versus those that did not. Similarly, 18% increases in strength and a 46% decrease in hamstring injury incidence were found in a small group of female soccer players who undertook a 10 week hamstring strengthening in comparison to those that did not (Askling et al., 2003). Combined together, these studies consistently show that increased muscular strength has a consistent beneficial effect on injury risk.

Conversely, it has also been suggested that soccer players with superior power output capability may be at a higher risk of injury (Henderson et al., 2010; Arnason et al., 2004; Engebretsen et al., 2010). Henderson et al. (2010) found that the odds of a hamstring injury increased by 1.47 for every extra 1 cm jumped on a non-countermovement jump in Premier League soccer players, whilst Engebretsen et al. (2010) highlighted a quicker 40 m sprint time as a risk factor for groin injury in soccer players. Although Arnason et al. (2004) also found a trend towards higher power output through squat testing in soccer players who subsequently sustained groin injuries versus those that did not, both Engebretsen et al. (2010) and Arnason et al. (2004) found no correlations between injury incidence and countermovement or non-countermovement jump heights in soccer players. Therefore, the role of power output in injury incidence in soccer warrants more research to establish its influence.

2.5.3 Lower limb bilateral asymmetries and injury incidence in soccer

Whilst absolute strength and power of the lower limbs is an identified potential risk factor for injury, bilateral power asymmetries have also been shown to increase injury risk in soccer players (Burkett, 1970; Yamamoto, 1993; Orchard et al., 1997; Croiser et al., 2008) with the concept that a weaker leg relative to the contralateral leg may predispose the weaker muscle groups to an elevated risk of injury (Opar et al., 2012).

Indeed, when asked to identify risk factors for injury, elite level soccer practitioners reported bilateral asymmetry as the 3rd most important non-contact risk factor for injury (McCall et al., 2014) highlighting its importance in the applied environment.

Lower limb bilateral asymmetry and injury risk was originally researched in track and field where it was found that athletes who had sustained previous hamstring injuries had significant bilateral knee flexor strength differences whilst athletes that remained injury free did not (Burkett, 1970). Following on from this, Yamamoto (1993) found that over two year period, track and field athletes who suffered hamstring injuries had significantly larger pre-season bilateral knee flexor and extensor strength differences than those that did not get injured. Similarly, in research looking at athletes from a range of sports (soccer, martial arts and track and field), who had experienced some form of hamstring strain in the previous 10 months, over 50% of them were found to have bilateral asymmetries of greater than 15% (Croisier et al., 2002). Additionally, following treatment to decrease asymmetries to below 5%, no further hamstring injuries were picked up in the following 12 months, suggesting that balanced lower limb strength profiles may reduce muscle injury risk. When looking specifically at soccer, Croisier et al., (2008) found that after assessing correlations between pre-season isokinetic testing and season-long injury incidence in 687 professional footballers, individuals with unaddressed bilateral strength asymmetries had 4.7 times greater risk of hamstring injury than those without asymmetry. Additionally, individuals who had asymmetries that were corrected for reduced their risk of hamstring injury to 2.9 times higher than individuals with no asymmetry. This was also supported by Fousekis et al., (2010) who found that players with specifically high eccentric hamstring or quadriceps asymmetries were at a significantly greater risk of muscle strain than those without.

Whilst the published research seems to suggest a correlation between increasing bilateral asymmetry and increased injury risk, all studies mentioned above have investigated leg bilateral asymmetry using maximal voluntary contractions of knee flexor and extensor using an isokinetic dynamometer. As mentioned previously, it has been suggested that these maximal contractions of the hamstring and quadriceps muscles may not be representative of the functional actions in soccer (Newton et al., 2006) and therefore that the asymmetry values gained may not provide an appropriate

indication of the function of the lower limbs muscles during football movements, potentially limiting the correlation of any results to lower limb soft tissue injuries. Additionally, although Croisier et al. (2008) defined bilateral asymmetry of 15% as ‘significant’ for affecting injury risk, there is little consensus within soccer specific research as to whether there is a critical threshold value for bilateral asymmetry that correlates with an increased risk of injury. Therefore, to accurately define the impact of any given asymmetry, the effect of asymmetries of varying degrees on injury risk needs to be classified (Menzel et al., 2013).

Therefore, it appears that research investigating the relationship between lower limb bilateral asymmetry and injury incidence in soccer players utilising movements with greater applicability to soccer is needed. Chapter 7 of this thesis aims to do this through investigating the correlation between pre-season maximal seated leg press testing and subsequent season long injury incidence.

In summary, this thesis aims to:

- Establish the reliability and limits of meaningful change of soccer players using the Keiser Air420 seated leg press protocol.
- Establish typical characteristic lower limb strength, power and bilateral asymmetry values for a soccer player, dependent on playing position and playing age group.
- Investigate the variations across a soccer season in lower limb strength, power and asymmetry dependent on playing age group.
- Investigate impact of soccer match play induced fatigue on lower limb strength, power and asymmetry.
- Investigate the correlation between lower limb strength, power and asymmetry and injury incidence over a soccer season.

CHAPTER 3: GENERAL METHODOLOGY

3.1 *Testing Procedures*

For all research chapters, participants completed a progressive maximal pneumatic resistance seated leg press test on a Keiser Air420. The testing procedure, outlined in Table 3.1 using example resistances, involved completing multiple repetitions of leg press movement through progressive incremental resistances from a seated position (approximately 90° knee flexion) with feet flat on each footplate as seen in Figure 3.1.

Prior to completing a test, to act as a standardised warm up, participants completed a 5-min cycle at approximately 60-75 Watts on a cycle ergometer (Keiser M3+, Keiser Corporation, California) followed by ten bodyweight squats and three countermovement jumps. Once participants were seated on the leg press, the depth of the seat was adjusted to ensure the appropriate seating position. As participants were prone to adjust their position to produce more force at heavier resistances, seating position was explained to participants prior to each test and continually observed and reinforced throughout each test also.

The testing protocol is pre-programmed into the machine and was initiated by inserting a magnetic chip into the resistance display screen and holding down the increase and the decrease resistance buttons simultaneously for 5 seconds. Following this, on-screen resistance was adjusted in order to set the required resistance at 10th repetition for the current test. Once this was completed, the machine automatically decreased resistance to that required for the 1st warm up repetition. Resistance set on the 10th repetition was programmed dependent on each participant's performance in previous exposure tests and pre-programmed resistance increments in-between each repetition were automatically calculated by the machine dependent on 10th repetition resistance set.

Prior to the 1st recorded repetition of each test, 2 warm up repetitions at the starting weight were completed. Following completion of the 1st recorded repetition, resistance on each repetition and rest period between repetitions automatically increased incrementally until failure, with 'Maximal Resistance' pushed defined as the final load that could be moved to full knee extension with both legs whilst maintaining proper seating position (McDonagh and Davies, 1984). As participants

were encouraged to work until maximal resistance was reached, the total number of repetitions completed differed between participants. Participants were asked to complete each repetition through extending both legs together with maximum velocity and instruction to ‘push as fast and as evenly as possible’. During rest periods between reps, participants were allowed, but not instructed, to remove their feet from the foot plates, but remained seated at all times. Participants knew the resistance that they were attempting next and received an instantaneous average power feedback following each repetition but at no point were encouraged to use this feedback to affect their results.

Once a full test was completed, the magnetic chip was removed from the machine and single leg force, velocity and power output for each all repetitions was automatically uploaded and saved to Keiser’s software programme on an adjacent desktop computer. From here, data files were exported and imported for further analysis relevant in each study. All trials completed in the study were conducted by the same investigator.



Figure 3.1: Example seating position at rest on the Keiser Air420 seated leg press

3.2 Testing variables

For each repetition, peak force, velocity and power were recorded for each leg. Power output calculated for each repetition is a product of velocity and force registered in the air cylinders. Force is calculated from the increase in air pressure following initial movement at the footplates whilst velocity is calculated from the distance the cylinders move over time from their rest position to their furthest point (when participant is at full knee extension). Resistance set for each repetition and displayed

on the feedback screen is the force measured in the air cylinder at a set point in the range of motion of the footplate.

For each test, variables recorded were:

- **Maximal Resistance** defined as final resistance moved with both legs to full knee extension whilst maintaining proper seating position, chosen as a marker of strength capacity.
- **Peak Power** defined as the highest power output from each test for both left and right legs individually, chosen to highlight maximal power output from the test.
- **Average Power** defined as the average of all power outputs for both left and right legs individually, chosen to show an overview of power output across a wide range of resistances.
- **Last 4 Repetition Average Power** defined as average of the power output from the last 4 repetitions for both left and right legs individually (See Figure 3.2). This variable was chosen for analysis as a marker of power output at high strength resistance.
- **Maximal Velocity (Velocity Max)** calculated from extrapolating a linear trend line plotted through all force-velocity data points to 0 N force for both left and right legs individually, chosen as a marker of maximal speed of movement.
- **Maximal Force (Force Max)** calculated from extrapolating a linear trend line plotted through all force-velocity data points to 0 m/s velocity for both left and right legs individually (See Figure 3.3), chosen as a marker of maximal strength capacity.

Peak Power Combined, Average Power Combined, Last 4 Repetition Average Power Combined, Force Max Combined and Velocity Max Combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

Table 3.1: Keiser Air420 example 10 repetition maximal power test protocol

Repetition Number	1st Warm Up	2nd Warm Up	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	All Subsequent Reps
Resistance (kg) based on 250 kg 1RM	41**	41	41	64	87	110	133	157	180	203	226	250	Previous rep+23.2*
Rest Period (s)	3.0	3.0	3.0	4.2	5.8	8.1	11.4	15.8	22.1	30.8	43.0		60.0

***Rep to rep Resistance Increase = (Maximal Resistance¹ selected-18.14)/10**

**** Starting Resistance = Resistance Increase + 18.14**

¹Maximal Resistance selected based on maximal strength attained in familiarisation trails

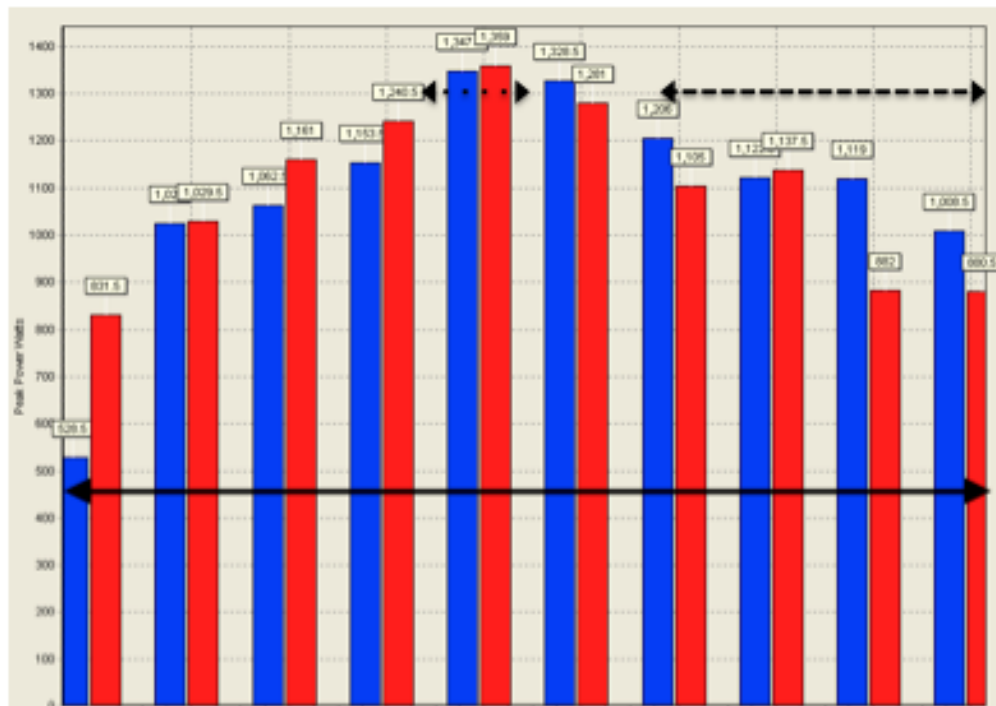


Figure 3.2: Example Keiser Air420 power output graph across increasing resistances.

Blue bars show left leg power output and red bars show right leg power output. Arrows highlight values used for power output variables. Bold- Average Power, Dashed- Last 4 Repetition Average Power, Dotted- Peak Power

3.3 *Asymmetry calculations*

To assess for potential differences in asymmetry calculations, in Chapter 4, bilateral power asymmetry scores were calculated for Peak, Average and Last 4 Repetition Average Power in three different ways: Absolute Differences, Percentage Differences and Symmetry Angle.

Absolute Differences were calculated using the following equation:

$$RIGHT\ LEG - LEFT\ LEG$$

Percentage Differences were calculated similar to previous studies (Impellizzeri et al., 2007) using the following equation:

$$\left(\frac{RIGHT\ LEG - LEFT\ LEG}{MAXIMUM\ VALUES\ PRODUCED\ BY\ RIGHT\ OR\ LEFT\ LEG} \right) \times 100$$

Symmetry Angles were calculated similar to previous research (Zifchock et al., 2008) using the following equation:

$$\left\{ \frac{45 - \arctan\left[\frac{left}{right}\right]}{90} \right\} \times 100$$

For chapter 4, across all three calculations, any positive results denoted right dominance and negative results denote left dominance.

For all subsequent chapters, asymmetry calculations were refined following results of reliability testing. Additionally, for chapters 5,6 and 7, all bilateral asymmetry variables were calculated to denote a positive number regardless of left or right leg power dominance. This asymmetry calculation method was been taken to give a true reflection of the magnitude of bilateral asymmetry amongst the sample so individuals with ‘negative’ dominant asymmetries did not cancel out individuals with ‘positive’ dominant asymmetries which may result in an inappropriate and uninformative average values.

Participants completed the progressive maximal pneumatic resistance seated leg press test detailed as above across all chapters of the thesis, however as all the research questions investigated differed in their approach, any additional testing that was completed and all methodological considerations unique to each study are presented in their respective chapters along with the relevant statistical analysis information.

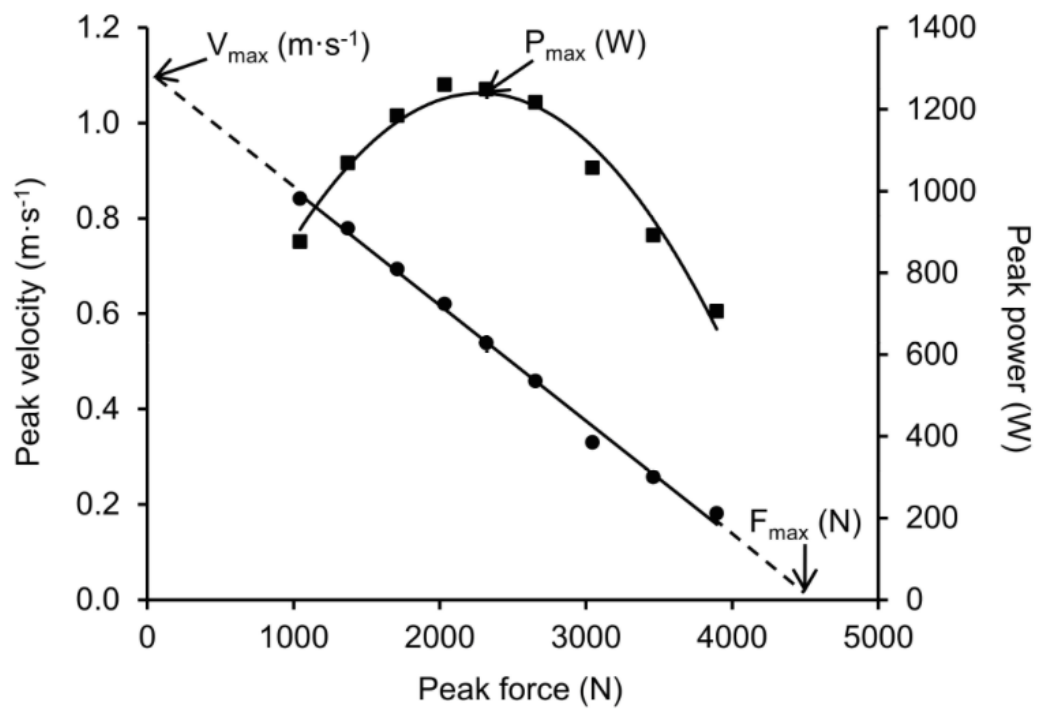


Figure 3.3: Example single leg force-velocity and power output relationship

Square markers: power output data points, circle markers: force-velocity data. Solid lines: line of best fit through each respective data point, dashed line: extrapolation to calculate Velocity Max and Force Max

CHAPTER 4: ESTABLISHING THE RELIABILITY AND LIMITS OF MEANINGFUL CHANGE OF LOWER LIMB STRENGTH AND POWER MEASURES DURING SEATED LEG PRESS IN ELITE SOCCER PLAYERS

4.1 Introduction

Leg strength and power are important physical attributes for soccer, both for competent skill execution (Cabri et al., 1988; Cometti et al., 2001) and injury prevention (Henderson et al., 2010, van Beijsterveldt et al., 2013). In particular, low absolute strength values and left-right leg strength/power asymmetries are commonly associated with increased injury risk in soccer (Croisier et al., 2002; Knapik et al., 1991; Engebretsen et al., 2010). Measurements of leg strength, power and asymmetry can be an important tool to assess an athlete's physical ability, and to monitor changes that occur with training or detraining.

For practitioners to have confidence in any test, results attained from it must be considered reliable and have established ranges of meaningful change- defined as the expected natural variation around a test, needed to establish if longitudinal change can be considered 'real'. The reliability of leg strength and power assessment protocols has been reported extensively. Various studies investigating reliability of double leg jumps including un-resisted and resisted countermovement jumps (Nuzzo et al., 2011, Young et al., 1997), squat jumps (Ortega et al., 2008) and broad jumps (Ortega et al., 2008, Wiklander and Lysholm, 1987) have reported test-retest coefficients of variations (CV) between 1.8%-6.0% and intraclass correlation coefficient (ICC) values between 0.88-0.93, with all studies suggesting that double leg jump tests show 'very strong' test-retest reliability.

As the majority of movements in sport (e.g. running, cutting and kicking) involve single leg loading (Fousekis et al., 2010, Reilly, 1996), to improve specificity of testing single leg jump testing has also been utilised across the literature as a lower limb strength and power assessment protocol. As such, various single leg hop tests such as horizontal distance (Bandy et al., 1994; Paterno and Greenberger, 1996), vertical hop and triple hop for distance (Munro and Herrington, 2011) have also been assessed for reliability. These studies consistently show 'very strong' reliability, with

ICC values between 0.76-0.96 and no significant differences between any repeated tests. Test-retest reliability of left-right leg asymmetries obtained through single leg hops has been reported to be ‘very strong’ (ICC > 0.81) in some studies (Hopper et al., 2002; Reid et al., 2007), although Risberg et al. (1995) found that a 21% change in performance was needed to establish significance due to the variation they found between repeated tests (7.7% coefficient of variation-CV). Differences in findings may be due to large learning effects associated with single leg jumps (Bogla and Keskula, 1997; Booher et al., 1993), suggesting that extensive familiarisation to the movement technique may be required particularly for adolescent athletes. Additionally, due to the necessity to bear load through hip, knee and ankle joints, the use of double and single leg jumps as a measure of lower limb power can be limited with load-compromised individuals and alternative offloaded protocols with greater control of movement are useful for testing in the elite environment.

Isokinetic dynamometry is also commonly used to assess lower limb strength and power and has consistently been found to elicit ‘very strong’ to ‘nearly perfect’ test-retest reliability with ICC values between 0.71-0.99 tested over a range of velocities and muscle actions (Abernethy et al., 1995; Gleeson and Mercer, 1992; Li et al., 1996; Pincivero et al., 1997). However, studies assessing the reliability of left-right leg strength/power asymmetries obtained through isokinetic dynamometry have found weaker reliability with ICC values ranging between 0.29-0.78 and standard error of mean (SEM) between 3.2% to 8.7% (Impellizzeri et al., 2007, Impellizzeri et al., 2008). Isokinetic dynamometry also lacks applicability to sporting movement (Cometti et al., 2001), has low correlation with other sports performance measures (Mognoni et al., 1994) and can be time consuming to complete. Therefore, isokinetic dynamometry may not be an applicable lower limb assessment tool for soccer players.

The Keiser Air420 seated leg press (Keiser Corporation, Fresno, CA) is a pneumatic resistance-based seated leg press machine with the left and right footplates that move independently of each other. Movement from a seated position with feet elevated enables non-weight bearing loaded maximal strength and power testing utilising movements that may be considered more applicable to the sporting environment than isokinetic dynamometry, overcoming many of the aforementioned issues. However, to date, there has only been one study investigating the reliability of the Keiser Air420 (LeBrasseur et al., 2008), which found a non-statistically

significant increase in maximum resistance of 1.1% and ‘nearly perfect’ test-rest reliability (ICC: 0.990) between 2 trials. However, reliability was not established for single or double leg power values or for left-right leg asymmetries, and as participants were classified as healthy males (age range 37-70 y), the findings cannot be generalizable to an elite soccer population.

Accordingly, the current study aimed to establish the reliability of double leg maximal strength, single leg and double leg power and left-right power asymmetries in elite soccer players using a seated leg press. Additionally, the study aimed to quantify the magnitude of change between tests that can be confidently established as outside of the range of natural variability of the test.

4.2 Methodology

4.2.1 Experimental approach to the problem

The current study used a repeated test-retest protocol in which participants undertook an incremental resistance leg press test on three separate occasions to assess for variation between tests. Each test was completed at least 72 hours following and within 192 hours of the individuals’ previous test (mean interval of 132 ± 43 hours). Tests took place prior to a training session, occurred at the same time of day, following a day consisting of minimal or no physical stimulus (< 4000 m total distance, < 50 m high intensity distance and < 5 minutes above 85% max heart rate) established through GPS monitoring (Statsports Viper, Statsports Technologies Ltd, N.Ireland) and greater than 60 hours following a competitive match or lower limb strengthening session. The testing period was specifically selected as a period in the season when on-field conditioning was at its most consistent day-to-day and week-to-week.

4.2.2 Subjects

Thirteen elite male professional soccer players (Age: 18.4 ± 0.8 y, height: 179.0 ± 9.2 cm, weight: 72.1 ± 6.7 kg, body fat: $9.6 \pm 1.4\%$, VO₂ max: 58.1 ± 1.3 ml/kg/min) volunteered for this study. A small sample size was considered acceptable due to the elite level of participants and is in line with previous research conducted within the research field (Bandy et al., 1994; Li et al., 1996). All participants were playing full time academy soccer for the same Premier league football club for a minimum of 9

months prior to testing. Inclusion criteria were that they were injury free (defined as a 'time loss injury' as classified in a consensus statement on injuries within soccer (Fuller et al., 2006)) for the duration of the testing period and that they had previously completed a minimum of three exposures to the testing protocol. All participants were regularly participating in soccer training sessions and lower limb gym strengthening sessions between tests and all were exposed to similar physical stimulus over this period. The study obtained ethical approval from the School of Health Research Ethics Approval Panel at University of Bath and all participants were informed of the potential benefits and risks of the research prior to providing informed consent. For participants under the age of 18 (age range: 16.8-19.5 years), parental informed consent was also obtained.

4.2.3 Procedures

On each testing occasion, the testing procedure was completed as outlined in Chapter 3: General Methodology.

Regardless of the number of repetitions in each test (Mean \pm SD: 11.2 \pm 0.9), Peak Power (the highest power output from each test for each leg), Average Power (the average of all power outputs for each leg) and Last 4 Repetition Average Power (the average of the power output from the last 4 repetitions of each test for each leg) variables were recorded for each test. Velocity Max and Force Max are calculated by creating a line of best fit against the velocity-force values calculated on each repetition for each leg and then extrapolating back to 0kg resistance and 0m/s velocity for Velocity Max and Force Max respectively as shown in Figure 3.3.

Peak Power Combined, Average Power Combined, Last 4 Repetition Average Power Combined, Force Max Combined and Velocity Max Combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

4.2.4 Asymmetry calculations

As detailed in Chapter 3: General Methodology, bilateral power asymmetry scores were also calculated for Peak, Average and Last 4 Rep Average Power in three different ways- Absolute Differences, Percentage Differences and Symmetry Angle. Calculating Absolute Differences were calculated using the following equation:

RIGHT LEG – LEFT LEG

Percentage Differences were calculated similar to previous research (Impellizzeri et al., 2007) but with adjustment of numerator to account for critique by Bishop et al. (2016). Percentage Difference was calculated using the following equation:

$$\left(\frac{RIGHT\ LEG - LEFT\ LEG}{MAXIMUM\ VALUES\ PRODUCED\ BY\ RIGHT\ OR\ LEFT\ LEG} \right) \times 100$$

Symmetry Angles were calculated similar to previous research (Zifchock et al., 2008) using the following equation:

$$\left\{ \frac{(45 - \arctan[\frac{left}{right}])}{90} \right\} \times 100$$

For all calculations, any positive results denoted right dominance and negative results denote left dominance.

4.2.5 Statistical Analyses

Data were analysed using Microsoft Excel (Microsoft, Redmond, WA) and statistical package SPSS (Version 17.0; Chicago, IL) and all data are presented as mean \pm standard deviation. Paired samples t-tests were used to determine if significant differences existed between consecutive tests (Test 1-Test 2 and Test 2-Test 3). Within-subject reliability was assessed with the use of a two-way mixed model ICC (3,1) and typical error, which was expressed as both a percentage and as an absolute value (TE) for raw data values. Only TE was used for bilateral asymmetry values as taking a percentage error value of a small percentage value produces values that may mislead and therefore were considered inappropriate. The strength of relationships for ICC coefficients was classified as: $0.3 \leq r < 0.5$ was ‘poor’, $0.5 \leq r < 0.75$ was ‘moderate’, $0.75 \leq r < 0.9$ was ‘good’ and $0.9 \leq r < 1.0$ was ‘excellent’ (Koo and Li, 2016).

To establish the limits for meaningful change around data, the mean of the outcome variable across all 3 tests $\pm 1.75 \times TE$ for the outcome variable was used (Hopkins, 2000).

The data were considered for heteroscedasticity by plotting difference between consecutive tests results (Test 1-Test 2 and Test 2-Test 3) against averaged results

from the respective tests. A moderate trend towards heteroscedasticity was found for Last 4 Rep power variables ($r^2 = 0.002-0.479$) and therefore, for TPE calculations for these variables, data was log transformed.

4.3 Results

4.3.1 Lower limb strength and power

To establish reliability, change in strength and power variables (Mean \pm SD) across all 3 tests was calculated. No significant differences were found between Test 1-Test 2 or between Test 2-Test 3 for any variables ($p > 0.156$) (Table 4.1)

Between Test 1-Test 2, all variables showed percentage typical error values $< 7.1\%$ and ICC > 0.806 , and between Test 2-Test 3, all variables showed percentage typical error values $< 7.0\%$ and ICC > 0.849 . When establishing reliability across all 3 tests, all variables showed percentage typical error values $< 6.9\%$ with ICC values > 0.762 (Table 4.2).

4.3.2 Lower limb bilateral asymmetry

To establish reliability of lower limb asymmetry variables, mean change across all 3 tests was calculated (Table 4.3). Between Test 1 and Test 2, significant differences were found for % Difference Last 4 Repetitions and Symmetry Angle Last 4 Repetitions ($p < 0.033$) whilst all other asymmetry variables were not significantly different ($p > 0.055$). No significant differences were found for any asymmetry variables between Test 2 and Test 3 ($p > 0.288$).

Comparing Test 1-Test 2 and Test 2-Test 3, Average Power and Last 4 Rep Power Asymmetry values established ICC values > 0.780 and Peak Power Asymmetry variables established ICC values < 0.768 . Combining all 3 tests (Table 4.4) Average Power and Last 4 Rep Power asymmetry values established ICC values > 0.843 with Peak Power asymmetry variables established ICC values < 0.647 .

TE values show percentage difference variations of between 2.07-3.56, Symmetry Angle variations between 0.69-1.19 and Absolute Difference variations between 20.0-45.04 (Table 4.4). Across all calculations, Average Power asymmetry values (% Difference Average, Difference Average and Symmetry Angle Average) produced the narrowest TE values.

Table 4.1: Mean (\pm SD) for various strength and power variables for Test 1, Test 2 and Test 3 and the change between pair of trials

	Test 1 Mean \pm SD	Test 2 Mean \pm SD	Test 3 Mean \pm SD	Change Test 1-Test 2 Mean \pm SD	Change Test 2-Test 3 Mean \pm SD
Max Resistance (kg)	315 \pm 41	328 \pm 55	329 \pm 53	-11.8 \pm 28.1	-1.9 \pm 22.0
Velocity Max Combined (m/s)	3.66 \pm 0.51	3.57 \pm 0.47	3.55 \pm 0.48	0.09 \pm 0.30	0.02 \pm 0.24
Velocity Max Left (m/s)	1.82 \pm 0.26	1.76 \pm 0.23	1.77 \pm 0.24	0.58 \pm 0.17	-0.09 \pm 0.13
Velocity Max Right (m/s)	1.84 \pm 0.25	1.81 \pm 0.25	1.79 \pm 0.25	0.03 \pm 0.14	0.02 \pm 0.12
Force Max Combined (N)	3211 \pm 438	3308 \pm 460	3256 \pm 546	-97 \pm 163	52 \pm 195
Force Max Left (N)	1614 \pm 207	1665 \pm 215	1636 \pm 260	-51 \pm 104	29 \pm 105
Force Max Right (N)	1597 \pm 242	1643 \pm 254	1620 \pm 291	-46 \pm 77	23 \pm 98
Peak Power Combined (W)	2276 \pm 315	2321 \pm 307	2287 \pm 407	-45.6 \pm 142.6	34.8 \pm 179.9
Peak Power Left (W)	1123 \pm 154	1149 \pm 163	1138 \pm 196	-25.2 \pm 88.5	10.8 \pm 92.9
Peak Power Right (W)	1152 \pm 171	1173 \pm 151	1149 \pm 217	-20.4 \pm 68.0	24.0 \pm 96.7
Average Power Combined (W)	1879 \pm 270	1884 \pm 260	1847 \pm 281	-5.1 \pm 157.5	37.1 \pm 112.4
Average Power Left (W)	925 \pm 136	931 \pm 128	913 \pm 134	-5.8 \pm 80.5	17.5 \pm 63.9
Average Power Right (W)	954 \pm 139	953 \pm 138	933 \pm 152	0.7 \pm 78.7	19.6 \pm 52.7
Last 4 Rep Ave Power Comb (W)	2015 \pm 341	2010 \pm 306	1944 \pm 354	5.1 \pm 196.3	65.9 \pm 164.7
Last 4 Rep Ave Power Left (W)	984 \pm 170	991 \pm 158	957 \pm 171	-6.9 \pm 91.0	34.4 \pm 90.7
Last 4 Rep Ave Power Right (W)	1031 \pm 183	1019 \pm 161	987 \pm 196	12.0 \pm 107.2	31.5 \pm 85.1

Table 4.2: Test 1-Test 2-Test 3 average typical error values and combined ICC values

	Average Typical Error		ICC (95% CI)
	Absolute	Relative	
Max Resistance (kg)	17.7	5.9%	0.893 (0.755-0.963)
Velocity Max Combined (m/s)	0.19	5.4%	0.792 (0.564-0.924)
Velocity Max Left (m/s)	0.1	5.8%	0.762 (0.513-0.912)
Velocity Max Right (m/s)	0.09	5.2%	0.815 (0.605-0.933)
Force Max Combined (N)	127	4.2%	0.914 (0.799-0.970)
Force Max Left (N)	74	5.1%	0.881 (0.731-0.959)
Force Max Right (N)	62	3.9%	0.928 (0.830-0.975)
Peak Power Combined (W)	114.1	5.2%	0.886 (0.740-0.960)
Peak Power Left (W)	64.1	5.8%	0.851 (0.671-0.947)
Peak Power Right (W)	58.2	5.3%	0.898 (0.765-0.965)
Average Power Combined (W)	95.4	5.4%	0.866 (0.701-0.953)
Average Power Left (W)	51.1	6.0%	0.846 (0.663-0.945)
Average Power Right (W)	46.5	5.0%	0.884 (0.737-0.960)
Last 4 Rep Ave Power Combined (W)	127.1	6.4%	0.867 (0.702-0.953)
Last 4 Rep Ave Power Left (W)	64.3	6.9%	0.867 (0.703-0.953)
Last 4 Rep Ave Power Right (W)	68.0	6.5%	0.864 (0.696-0.952)

Table 4.3: Mean (\pm SD) for bilateral asymmetry variables for Test 1, Test 2 and Test 3 and the change between pairs of trials

	Test 1 (Mean \pm SD)	Test 2 (Mean \pm SD)	Test 3 (Mean \pm SD)	Change Test 1-Test 2(Mean \pm SD)	Change Test 2-Test 3 (Mean \pm SD)
% Difference Peak	2.3 \pm 6.5	2.1 \pm 5.4	0.6 \pm 6.0	0.1 \pm 5.2	1.5 \pm 4.9
% Difference Average	2.9 \pm 5.7	2.1 \pm 5.7	1.8 \pm 6.0	0.7 \pm 2.3	0.4 \pm 3.6
% Difference Last 4 Repetitions	4.3 \pm 8.2	2.6 \pm 8.3	2.5 \pm 9.9	1.64 \pm 2.46*	0.1 \pm 6.1
Difference Peak (W)	29.0 \pm 79.8	24.3 \pm 68.0	11.1 \pm 72.1	4.73 \pm 67.58	13.19 \pm 59.80
Difference Average (W)	28.6 \pm 55.4	22.1 \pm 57.4	19.9 \pm 57.68	6.49 \pm 23.21	2.19 \pm 33.30
Difference Last 4 Repetitions (W)	46.3 \pm 90.2	27.4 \pm 89.6	30.3 \pm 100.8	18.92 \pm 32.08	-2.91 \pm 61.81
Symmetry Angle Peak (%)	0.766 \pm 2.17	0.707 \pm 1.78	0.215 \pm 1.99	0.06 \pm 1.73	0.49 \pm 1.63
Symmetry Angle Ave (%)	0.970 \pm 1.93	0.706 \pm 1.91	0.608 \pm 2.03	0.26 \pm 0.78	0.01 \pm 1.17
Symmetry Angle Last 4 Repetitions (%)	1.44 \pm 2.85	0.85 \pm 2.85	0.88 \pm 3.42	0.58 \pm 0.86*	-0.21 \pm 2.05

* Statistical difference ($p < 0.05$) between test 1 and test 2

Table 4.4: Test 1-Test 2- Test 3 average absolute typical error values and combined ICC values

	Average Absolute Typical Error	ICC (95% CI)
% Difference Peak	3.56	0.653 (0.350-0.864)
% Difference Average	2.07	0.874 (0.717-0.956)
% Difference Last 4 Repetitions	3.01	0.843 (0.656-0.944)
Difference Peak (W)	45.04	0.647 (0.342-0.861)
Difference Average (W)	20.0	0.881 (0.731-0.958)
Difference Last 4 Repetitions (W)	33.19	0.848 (0.666-0.946)
Symmetry Angle Peak (%)	1.19	0.657 (0.355-0.866)
Symmetry Angle Ave (%)	0.69	0.878 (0.725-0.957)
Symmetry Angle Last 4 Repetitions (%)	1.03	0.851 (0.671-0.947)

4.3.3 *Limits of meaningful change*

To establish the smallest significant change between tests, ranges of meaningful change for each variable were calculated from their respective TE values (Table 4.5). Alongside this, lower and upper limits of non-meaningful change placed around mean values have been calculated as an example. For bilateral asymmetry calculations, due to large TE values, peak asymmetry variables (% Difference Peak, Difference Peak and Symmetry Angle Peak) established the largest range of non-meaningful change whilst average asymmetry variables established the narrowest range.

Table 4.5: Range of meaningful change for all variables and example lower and upper limits based on mean values

	Range for meaningful change	Mean of all tests	Lower Limit of mean	Upper Limit of mean
Max Resistance (kg)	±31	324	293	355
Velocity Max Combined (m/s)	±0.33	3.59	3.26	3.92
Velocity Max Left (m/s)	±0.18	1.78	1.60	1.96
Velocity Max Right (m/s)	±0.16	1.81	1.65	1.97
Force Max Combined (N)	±222	3258	3036	3480
Force Max Left (N)	±130	1638	1508	1768
Force Max Right (N)	±109	1620	1511	1729
Peak Power Combined (W)	±200	2295	2095	2495
Peak Power Left (W)	±112	1137	1025	1249
Peak Power Right (W)	±102	1158	1056	1260
Average Power Combined (W)	+167	1870	1703	2037
Average Power Left (W)	±89	923	834	1012
Average Power Right (W)	±81	947	866	1028
Last 4 Rep Ave Power Combined (W)	±222	1990	1768	2212
Last 4 Rep Ave Power Left (W)	±113	977	864	1090
Last 4 Rep Ave Power Right (W)	±119	1012	893	1131
% Difference Peak	±6.2	1.7%	-4.5	7.9
% Difference Average	±3.6	2.3%	-1.3	5.9
% Difference Last 4 Repetitions	±5.3	3.0%	-2.3	8.3
Difference Peak (W)	±78.8	21.5	-57.3	100.3
Difference Average (W)	±35	23.5	-11.5	58.5
Difference Last 4 Repetitions (W)	±58.1	34.7	-23.4	92.8
Symmetry Angle Peak (%)	±2.1	0.6%	-1.5	2.7
Symmetry Angle Ave (%)	±1.2	0.8%	-0.4	2.0
Symmetry Angle Last 4 Reps (%)	±1.8	1.1%	-0.7	2.9

4.4 Discussion

The primary aim of the current study was to determine the reliability of lower limb strength, power and asymmetry obtained through seated leg press in elite soccer players. No significant differences were observed between consecutive tests for all lower limb strength and power variables, with the ICC values > 0.866 suggesting ‘good’ reliability. Average asymmetry variables (% Difference Average, Difference Average and Symmetry Angle Average) also showed no significant differences between tests, moderate TE values and high ICC values > 0.874 suggesting ‘good’ test-retest reliability. Peak asymmetry variables were found to have the lowest ICC values (< 0.657) and the highest TE values, whilst Last 4 Rep Asymmetry variables showed significant differences between Tests 1 and 2, limiting their reliability as applicable bilateral asymmetry measures. The current study also established ranges of non-meaningful change for all variables, to more accurately evaluate magnitude of change between tests. Peak asymmetry variables established the largest range ($\pm 6.2\%$) whilst average asymmetry variables established the narrowest range ($\pm 3.6\%$) of non-meaningful change.

In the current study, all lower limb strength and power variables showed ‘good’ reliability with no significant differences across any tests and therefore can be used with confidence in future research. In particular, Maximal Resistance showed ‘good’ reliability with an ICC value of 0.893 and TPE of 5.9%. This corresponds well with the only other published research on the reliability of the Keiser seated leg press, which found ‘nearly perfect’ reliability (ICC: 0.99) of Maximal Resistance values and non-significant increases of 1.1% between test 1 and test 2 (LeBrasseur et al., 2008). In the current study, all between-tests error values for single leg measurements ranged between 5.3-6.9%, similar to values seen in single leg hop (Risberg et al., 1995) and isokinetic dynamometry (Pincivero et al., 1997) reliability studies. Similarly, ICC results found in the current study for all strength and power variables (ICC: 0.846-0.898) correlate well with single leg hop (Bandy et al., 1994; Paterno and Greenberger, 1996) and isokinetic dynamometry (Gleeson and Mercer, 1992) reliability studies, showing ‘good’ reliability.

Average power bilateral asymmetry variables (% Difference Average, Difference Average and Symmetry Angle Average) were not significantly different between any tests, with ICC values > 0.874 , and the lowest TE values in comparison to all other

asymmetry variables. Therefore, all average difference variables can be considered the most reliable asymmetry measures and most applicable to be used in future research. Results for average difference variables in the current study are similar to that found in other studies assessing bilateral asymmetry reliability through single leg hops (Hopper et al., 2002, Reid et al., 2007) and isokinetic dynamometry (Impellizzeri et al., 2008). Although different error calculations were used between studies, the 2.1% TE seen in the current study is similar to SEM values seen for single leg hop tests of 3.0-5.6% (Reid et al., 2007) and for single leg isokinetic dynamometry of 3.2-8.7% (Impellizzeri et al., 2008).

In contrast, peak asymmetry variables (Difference Peak, % Difference Peak and Symmetry Angle Peak) resulted the lowest ICC values across all tests ($ICC < 0.657$) and the largest TE across all asymmetry variables, showing that peak asymmetry variables have the weakest reliability of all asymmetry variables. Similarly, % Difference Last 4 Repetitions and Symmetry Angle Last 4 Reps were shown to have significant differences between 1st and 2nd tests, suggesting low reliability of these bilateral asymmetry variables also. However, as no significant differences were found between 2nd and 3rd tests for either variables, it may be the case that greater familiarisation to heavier loads is needed to improve the reliability of last 4 repetition asymmetry values. Indeed, whilst reliability is yet to be confidently established, the current study shows that larger differences between left and right leg power are seen over the last 4 repetitions in comparison to all other asymmetry variables (Table 4.3), and it may be the case that power near maximal loads highlights an imbalance that power at lighter loads does not. Despite differences in calculations between Absolute Difference, Percentage Difference and Symmetry Angle bilateral asymmetry values, no differences were seen between test-retest results in the current study for any of the asymmetry calculations. Therefore, for clarity, any one of the calculation methods in the current study can be used to represent bilateral lower limb power asymmetry with selection of the most appropriate calculation based on what is considered most appropriate to the individual practitioner in the applied environment.

To accurately evaluate the magnitude of change between tests for future research, the current study also aimed to establish the range of non-meaningful change around each variable to quantify the natural variability of the participants and of the testing equipment. These values were calculated by multiplying the TE across all 3 tests for

each variable by 1.75 (Hopkins, 2000). For instance, for an individual with an Average Power of 2000 W, values beyond the range of 1833 W-2167 W (2000 ± 167 W) are likely a meaningful change rather than being due to variability in the individual or the testing equipment/protocol.

One limitation of the current study is the use of repeated t-tests, which may have increased the likelihood of type I error in the results. However, as ICC values were calculated as an additional measure of reliability between tests and as t-test results were needed to calculate typical error values for all variables, their use in the current study was deemed appropriate. Another limitation may be that the Keiser incremental resistance leg press protocol, which increases resistance in block increments dependent on the pre-determined Maximal Resistance (see Table 3.1), may be unable to identify subtle variations in an individual's strength and power. For example, a 10-repetition test with Maximal Resistance set at 300 kg will increase from 300 kg to 328 kg between repetitions. It is possible that this ~9% increase may be too great and result in failure even though improvements may be apparent between tests. However, in the context of the applied environment, the magnitude of this limitation of the testing protocol is not considered great enough to employ an alternative method with greater sensitivity, which would introduce time efficiency and practicality limitations of its own. Additionally, although movement completed in the testing modality is multiarticular in nature, as movements are completed in a seated position with a fixed trunk direct specificity in relation to soccer could be questioned.

The current study established the reliability of single and double leg strength and power output of elite soccer players over varying resistances as well as bilateral lower limb asymmetry obtained through the Keiser Air420 incremental resistance leg press protocol. There were no significant differences between three test-retest trials for all strength and power variables. Results from asymmetry calculations showed that average power asymmetry variables (% Difference Average, Difference Average and Symmetry Angle Average) offer a reliable form of calculating bilateral power asymmetry with no significant differences across all trials, 'good' ICC values, and the lowest TE of all asymmetry calculations. However, due to weaker test-retest results, Peak Power and Last 4 Repetition Asymmetry variables cannot be considered as reliable bilateral asymmetry measures. TE values found in the current study were also

used to establish appropriate ranges of meaningful change for all variables to better inform future testing.

4.4.1 Conclusion

The current study has established that maximal strength, single and double leg power output and average bilateral asymmetry of soccer players results obtained through a seated leg press protocol can show an acceptable level of reliability and therefore gives practitioners greater confidence in any results obtained through the current testing protocol. Additionally, establishing the limits of meaningful change ranges for all variables allows practitioners to derive a greater detailed, accurate evaluation on the magnitude of changes between repeated tests in soccer players.

CHAPTER 5: LOWER LIMB STRENGTH, POWER AND BILATERAL ASYMMETRY OF ELITE ACADEMY SOCCER PLAYERS: ESTABLISHING PLAYING SQUAD AND PLAYING POSITION DEPENDENT TYPICAL VALUES AND TYPICAL VARIATION WITHIN A SEASON

5.1 Introduction

The physical demands of soccer involve continual low intensity movement combined with frequent intermittent high intensity movements (Stølen et al., 2005). Intense explosive actions such as sprints, jumps, turns and striking the ball are very important movements in the context of player performance (Cometti et al., 2001), and the quality and speed of these movements are predominantly determined by an individual's lower limb maximal strength and power (Cabri et al., 1988; Reilly et al., 2000). High levels of lower limb strength have also been associated with decreased injury risk in soccer (Grace, 1985; Fleck and Falkel, 1986; Bangsbo, 1994), whilst lower limb bilateral asymmetries in lower limb strength and power have been associated with an increased injury risk in soccer players (Croisier et al., 2008; Tournay-Chollet et al., 2000). Therefore, in applied environments, lower limb strength and power warrants detailed testing and monitoring for both performance and injury risk purposes.

Normative lower limb strength and power of elite soccer players has been established extensively in the literature through assessment of vertical countermovement jumps (Hoff and Helgerud, 2004; Mujika et al., 2009; Thomas and Reilly, 1979; Wisloff et al., 2004), and isokinetic dynamometry (Gur et al., 1999; Kellis et al., 2001; Fousekis et al., 2010, Sliwowski et al., 2017). Similarly, bilateral asymmetries of between 2-10% have been established in elite soccer players using both isokinetic dynamometry and double leg jumps (Menzel et al., 2013; Impellizzeri et al., 2007; Fousekis et al., 2010; Brito et al., 2010). Significant increases in strength and power variables have also been positively correlated with increasing chronological and playing age (Amato et al., 2001; Kellis et al., 2001; Rochcongar et al., 1988; Gur et al., 1999), however, little is known about whether there are changes in bilateral asymmetries dependent on age, or over the course of a competitive season.

Positional differences in lower limb strength, power and asymmetry have also been investigated, and whilst some studies have found no differences between playing positions (Davis et al., 1992, Magalhães et al., 2004), multiple studies have described positional differences in lower limb strength and power. Midfielders, particularly central midfielders, produce poorer jump height performance and peak torque values than goalkeepers, defenders and strikers (Boone et al., 2012; Raven, 1976; Wisloff et al., 1998; Bangsbo, 1994; Arnasson et al., 2004; Tourney Chollet et al., 2005; Oberg et al., 1984; Śliwowski et al., 2017). Tourney-Chollet et al. (2005) established strength differences between dominant and non-dominant legs dependent on playing position, but research into differences in the magnitude of bilateral asymmetry dependent on playing positions is limited and warrants further investigation in order to better inform training prescriptions.

Identification of variations in lower limb strength and power of soccer players over a season is also of interest, particularly to a practitioner, to assist in evaluation of a training programme as well as identification of periods in which fatigue and therefore injury risk may be elevated. However, studies of collegiate age and adult soccer players have been conflicting, with some studies reporting significant improvements over a season (Caldwell and Peters, 2009; Eniseler et al., 2012; Lehnert et al., 2014) whilst others have observed no significant differences at any time point (Thomas and Reilly, 1979; Casajús, 2001; Silvestre et al., 2006). Although research is limited, bilateral power asymmetries have also been found to remain unchanged across a season (Eniseler et al., 2012), but the effect of age on seasonal variation of lower limb strength, power and asymmetry is unknown.

Whilst extensive research has been completed into lower limb strength and power in soccer players, many questions remain. Additionally, studies have assessed strength and power through isokinetic dynamometry, which is criticised for lack of specificity to sporting movements (Commetti et al., 2001), or analysis of jump performance, which is greatly influenced by technique (Bolgla et al., 1997). Therefore, investigation of playing position and playing squad dependent lower limb strength, power and bilateral asymmetry of soccer players and its variation across a season through alternative robust, applicable testing methods is of interest to practitioners. The Keiser Air420 (A420) is a pneumatic resistance-based seated leg press machine

that is used extensively in the applied environment, however, to date, no research has been published establishing typical characteristic data for soccer players using the Keiser Air420.

Therefore, the aims of the current study were: (1) To establish double leg strength, power and bilateral power asymmetry characteristic data for elite soccer players through seated leg press. (2) To determine how playing position and playing age group affect the lower limb physical characteristics of elite soccer players. (3) To investigate fluctuations in strength, power and asymmetries of elite soccer players across a playing season.

5.2 Methodology

5.2.1 Typical characteristic strength, power and asymmetry assessment

Sixty-two elite professional soccer players comprising of 6 goalkeepers, 10 central defenders, 11 full backs, 20 central midfielders, 10 wide midfielders and 6 strikers (Age: 17.9 ± 1.4 years, height: 177.5 ± 8.4 cm, weight: 71.7 ± 8.2 kg, body fat: $9.8 \pm 1.4\%$) volunteered for this study. All participants were playing full time academy standard soccer for the same premier league football club and were either training within the U21 Squad (1 tier below the First Team, $n=20$ participants) or the Scholar Squad (2 tiers below the First Team), which is divided into 2 sub-groups, the U17 playing age group ($n=22$ participants) and U18 playing age group ($n=20$ participants - see Table 5.1). Inclusion criteria were that they were injury free (defined as a 'time loss injury' as classified in a consensus statement on injuries within soccer (Fuller et al., 2006)) at the testing period, had not sustained a serious injury (unable to participate in full squad training for > 8 weeks) preceding the testing period and that they were familiarised to the testing protocol with a minimum of 3 exposure trials prior to their first test. All participants were regularly participating in soccer training sessions and lower limb gym strengthening sessions between tests and all were exposed to similar physical stimulus over this period.

Participants undertook an incremental resistance leg press test at one single time point in the month of October and undertook countermovement jump measurement in the following December with the whole data set being collected over the course of 3

consecutive years. Across the testing period, each participant was only tested on 1 occasion so that all age groups are independent of each other.

Table 5.1: Playing age group and playing position participant breakdown

	U17	U18	U21
Goalkeeper (n=6)	2	2	2
Centre Back (n=10)	2	3	5
Full Back (n=11)	5	3	3
Central Midfielder (n=19)	8	5	6
Wide Midfielder (n=10)	4	4	2
Striker (n=6)	1	3	2
Totals (n= 62)	22	20	20

All tests occurred at the same time of day, following a day consisting of minimal physical stimulus or no physical stimulus (<4000 m total distance, <50 m high intensity distance and <5 minutes above 85% max heart rate) established through GPS monitoring (Statsports Viper, Statsports Technologies Ltd., N.Ireland) and greater than 48 hours following a competitive match or lower limb strengthening session.

For all participants, the incremental resistance leg press test was completed as described in Chapter 3: General Methodology following the testing procedure outlined in Table 3.1.

Following the same standardised warm up completed prior to the seated press test detailed in Chapter 3, participants completed three maximal countermovement jumps, with at least one minute of rest between jumps, using an optical jump mat (Optajump, Microgate, Italy). Participants were instructed to stand with feet placed at shoulder width apart and knees fully extended and to fix their hands at their hips. They were then instructed to jump as high as possible and were constantly monitored to ensure they maintained correct form. Only jumps that maintained form throughout were accepted and the highest of three jumps completed as recorded as the participants value. Due to injury between the two testing days, 5 players that completed the seated leg press test were unable to complete jump testing reducing sample size for this parameter to n=57.

Peak Power (the highest power output from each test for each leg) and Average Power (the average of all power outputs for each leg) variables were recorded for each test. Velocity Max and Force Max are calculated by creating a line of best fit against the velocity-force values calculated on each repetition for each leg and then extrapolating back to 0 kg resistance and 0 m/s velocity for Velocity Max and Force Max respectively as shown in Figure 3.3.

Peak Power Combined, Average Power Combined, Force Max Combined and Velocity Max Combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

Bilateral power asymmetry variables were calculated using average power variables through 2 different calculation methods: Absolute Differences and Percentage Differences. Both calculations are described in full in Chapter 3: General Methodology. Absolute Difference Average were calculated by taking the larger single leg average power output minus the smaller single leg average power output, whilst Percentage Difference Average was calculated by taking Absolute Difference Average divided by the larger single leg average power output and subsequently multiplying by 100 similar to previous studies (Impellizzeri et al., 2007).

Both power asymmetry variables have been calculated to denote a positive number regardless of left or right leg power dominance. This asymmetry calculation method has been taken to give a true reflection of the magnitude of bilateral asymmetry amongst the sample so individuals with ‘negative’ dominant asymmetries do not cancel out individuals with ‘positive’ dominant asymmetries which may result in an inappropriate and uninformative average values.

5.2.2 Seasonal fluctuations in strength, power and asymmetry assessment

A sub-group of 45 elite professional soccer players (Age: 17.5 ± 1.1 years, height: 176 ± 8 cm, weight: 71.0 ± 8.0 kg, body fat: $9.7 \pm 1.6\%$) comprising 4 goalkeepers, 5 central defenders, 11 full backs, 20 midfielders and 5 strikers from all 3 playing squads (U21: $n=10$; U17: $n=16$; U18: $n=19$) undertook the progressive resistance leg press test on three additional occasions across a football season. In addition to the October testing point, the sub-group completed tests at the start of July during the first

week of preseason training, at the start of January following a short Christmas break and at the start of April.

The same inclusion/ exclusion criteria mentioned in the main methodology were used for all tests. The same testing protocol detailed in the main methodology was used for all tests also, however maximal resistance set for each participant for each test was adjusted dependent on their previous maximal strength result attained to ensure all participants completed as close to 10 repetitions as possible.

5.2.3 *Statistical analysis*

Data was analysed using Microsoft Excel (Microsoft, Redmond, WA) and statistical package SPSS (Version 21.0; Chicago, IL) and all data are presented as mean \pm standard deviation. One-way ANOVA with Ryan-Holm Bonferroni post hoc comparison was used to assess differences in descriptive statistics. To evaluate the magnitude of differences between groups, Z-scores calculated with pooled variance standard deviation and their 95% confidence intervals were calculated for each playing squad and playing position in comparison to the mean of all players as a way of standardizing comparisons. Classification of effect size magnitudes was completed using Hopkin's modification of Cohen's magnitude inferences classification of < 0.2- trivial, 0.2-0.6- small, 0.6-1.2- moderate, 1.2-2.0- large, 2.0-4.0- very large, > 4.0 extremely large (Cohen 1988) combined with a magnitude based inference threshold of ± 0.2 established as the 'smallest worthwhile effect' (Batterham and Hopkins, 2006). An effect was deemed unclear if the likelihoods that the effect was substantially positive and negative were both $\geq 5\%$. Otherwise, the effect was deemed clear and was qualified with a probabilistic term using the following scale: 75-95% likely; 95-99.5% very likely; > 99.5% most likely. That is, only at least 'likely' effects were considered meaningful.

To assess seasonal fluctuations, differences in the mean for each time point in comparison to baseline (July) testing were calculated for the sub-group as whole and for their respective playing age groups and magnitude-based inferences were derived as described above (Batterham and Hopkins, 2006). Limits of meaningful change established through test-retest reliability testing (Chapter 4) were used to set thresholds for a practically important effect and using these, likelihood of effect

magnitudes were calculated as above. Limits of meaningful change were calculated as 1.75 multiplied by the typical error across 3 consecutive tests (Hopkins, 2000).

5.3 Results

5.3.1 Playing age group dependent strength, power and asymmetry

Anthropometric data for participants separated by playing age group was significantly different for age across all age groups. Players in the U21 squad were significantly taller than U18 squad (Table 5.2).

Table 5.2: Anthropometric descriptive participant statistics: playing age group

	All Participants (n=62)	U17 (n=22)	U18 (n=20)	U21 (n=20)
Age (years)	17.9±1.4	16.8±0.4 ^{ab}	17.6±0.4 ^{bc}	19.3±1.6 ^{ac}
Height (cm)	177.5±8.4	176.2±8.6	174.9±8.7 ^b	181.4±8.4 ^a
Weight (kg)	71.7±8.2	69.2±9.1	71.1±8.1	75.2±6.3
Body Fat (%)	9.8±1.4	9.8±1.2	9.8±1.3	9.7±1.7

^a- significant difference vs. U18; ^b-significant difference vs. U21, ^c- significant difference vs. U17

Typical characteristic lower limb strength and power results for an elite soccer player using the Keiser Air420 seated leg press can be seen in Table 5.3. Across all players, a 4.3±4.1% bilateral lower limb power asymmetry was found.

Playing age group dependent strength, power and bilateral asymmetry values can be seen in Table 5.3. For all variables, z-scores for each playing squad in comparison to the average for all players were less than 0.43. ‘Likely small’ effects were found for Average Power and Velocity Max variables for the U21 playing squad in comparison to the average of all players whilst all other variables for U21 squad and all variables for U17 and U18 squads showed ‘trivial’ effects sizes in comparison to the average of all players (Figure 5.1).

5.3.2 Playing position dependent strength, power and asymmetry

Anthropometric data for participants separated by playing position found that Goalkeepers and Centre Backs were significantly taller than all other playing positions. Additionally, Goalkeepers and Centres Backs were significantly heavier

than Full Backs, Centre Midfielders and Wide Midfielders and Goalkeepers had significantly higher body fat percentage than Full Backs and Wide Midfielders (Table 5.4).

Table 5.3: Playing age group dependent strength, power and asymmetry variables

	All Participants	U17 (n=22)	U18 (n=20)	U21 (n=20)
Maximal Resistance (kg)	332±69	324±83	345±67	327±56
Peak Power Combined (w)	2354±443	2237±503	2330±406	2507±382
Average Power Combined (w)	1908±350	1809±388	1873±306	2052±313
Velocity Max Combined (m/s)	3.72±0.40	3.62±0.40	3.67±0.29	3.89±0.45
Force Max Combined (N)	3306±620	3219±719	3335±578	3372±560
Absolute Difference Average (w)	43.1±47.4	29.8±24.9	46.5±58.2	54.4±52.7
Percentage Difference Average (%)	4.3±4.1	3.3±2.7	4.7±5.3	5.0±4.0
Jump Height (cm) §	56.3±6.3	56.0±5.7	56.8±6.9	56.0±5.7

§: n=57; U17: n=22, U18: n=18, U21: n=18.

Table 5.4: Anthropometric descriptive participant statistics: playing position dependent

	Goalkeepers (n=6)	Centre Backs (n=10)	Full Backs (n=11)	Centre Midfielders (n=19)	Wide Midfielders (n=10)	Strikers (n=6)
Age (years)	18.0±1.3	18.7±2.5	17.7±1.2	17.7±1.2	17.7±1.2	17.7±0.9
Height (cm)	189.6±3.2	185.4±5.0	175.3±6.0 ^{ab}	173.6±8.1 ^{ab}	174.2±6.2 ^{ab}	174.2±4.9 ^{ab}
Weight (kg)	79.6±5.9	79.5±7.3	69.2±5.0 ^{ab}	68.0±7.9 ^{ab}	68.6±6.8 ^{ab}	72.7±7.3
Body Fat (%)	11.4±1.2	10.0±1.6	9.2±1.8 ^a	9.7±1.2	9.2±0.8 ^a	9.9±1.0

^a-significant differences to Goalkeepers, ^b-significant differences to Centre Back

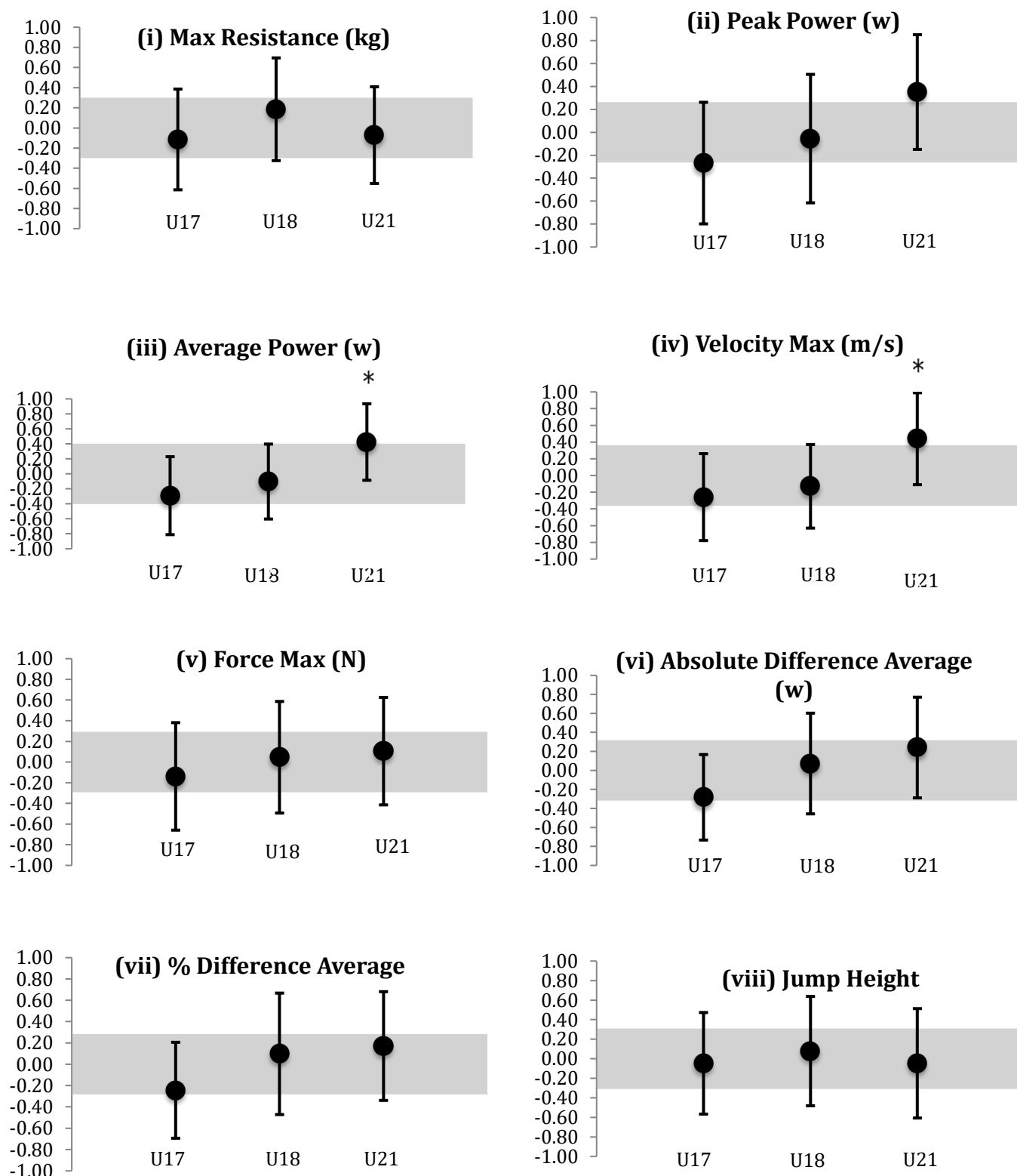


Figure 5.1: Z-score and 95% confidence intervals of strength, power and asymmetry values dependent on playing age group relative to the mean of all players.

Shaded area established around an effect size ± 0.2 to illustrate the band of 'trivial effect' for each variable. * denotes a 'likely small' effect.

Playing position dependent strength, power and asymmetry variables can be seen in Table 5.5. Comparing playing position dependent strength and power variables against the average of all players, z-scores established a ‘likely moderate effect’ for Centre Backs across four strength, power and asymmetry variables: Maximal Resistance, Average Power, Peak Power and Force Max, with ‘likely small effect’ seen for Absolute Difference Average and % Difference Average. ‘Likely moderate effect’ was also seen for Strikers for Max Resistance, Peak Power and Average Power and for Goalkeepers for Velocity Max. Additionally a ‘likely small effect’ for increased jump height in Wide Midfielders and ‘very likely small effect’ for decreased jump height for Centre Midfielders was also seen. Trivial effect sizes were seen for all other variables for all positions in comparison to the average for all players (z-score < 0.40- Figure 5.2).

5.3.3 *Seasonal Variation Data*

When assessing the group as whole, magnitude based inferences did not establish any ‘likely’ changes at any time point across the season (Table 5.6) for any strength, power and bilateral asymmetry variables.

When seasonal variation data was analysed dependent on playing squad, for U17 squad, ‘likely’ increases in Force Max were seen in January and ‘very likely’ increases in Force Max and ‘likely’ increases in Maximal Resistance and Peak Power were seen in April in comparison to July (Figure 5.3 and Figure 5.4). For U18 and U21 squads, magnitude based inferences did not establish any ‘likely’ changes at any point across the season.

Table 5.5: Playing position dependent strength, power and asymmetry variables

	All Participants (n=62)	Goalkeepers (n=6)	Centre Backs (n=10)	Full Backs (n=11)	Centre Midfielders (n=19)	Wide Midfielders (n=10)	Strikers (n=6)
Maximal Resistance (kg)	332±69	304±59	372±66	313±65	317±65	330±78	379±65
Peak Power Combined (w)	2354±443	2447±519	2658±385	2209±453	2187±354	2326±470	2593±432
Average Power Combined (w)	1908±350	1989±415	2159±316	1806±323	1783±280	1854±393	2083±335
Velocity Max Combined (m/s)	3.72±0.40	4.00±0.41	3.81±0.52	3.70±0.28	3.69±0.32	3.66±0.50	3.55±0.41
Force Max Combined (N)	3306±620	3143±542	3683±544	3079±624	3115±493	3326±786	3823±459
Absolute Difference Average (w)	43.1±47.4	35.7±21.5	70.7±82.8	41.3±25.0	33.1±27.2	30.2±24.7	60.8±83.1
Percentage Difference Average (%)	4.3±4.1	3.5±2.1	6.2±6.7	4.3±2.0	3.5±2.8	3.4±2.8	5.7±7.3
Jump Height (cm)§	56.3±6.3	55.8±7.1	58.0±5.4	58.5±8.5	52.2±3.7	60.3±5.9	55.8±3.6

§ n=57; GK: n=5, CB: n=9, FB: n=10, CM: n=18, WM: n=10, ST: n=5

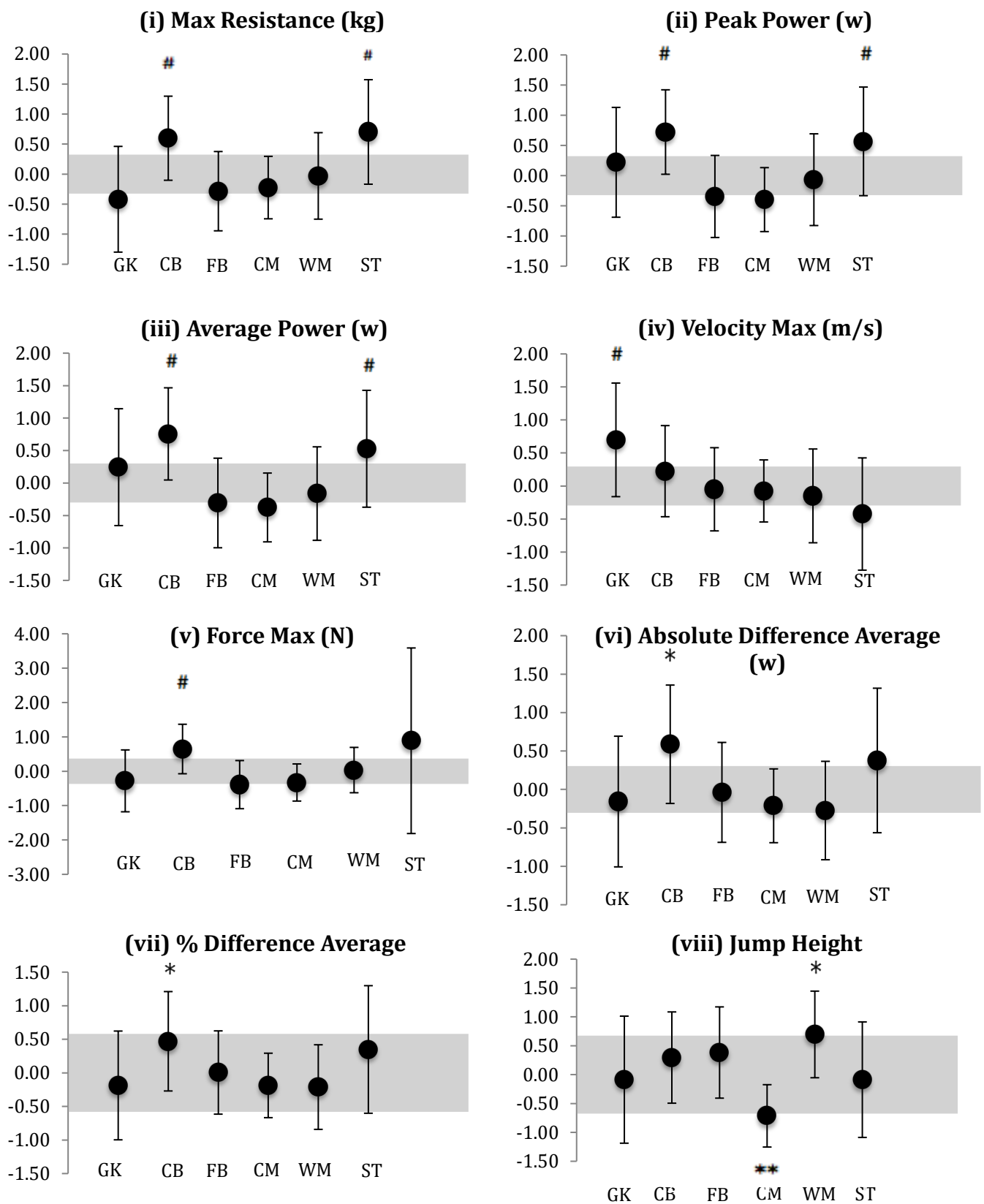


Figure 5.2: Z-score and 95% confidence intervals of strength, power and asymmetry values dependent on playing position relative to the mean of all players.

*denotes 'likely small' effect, **denotes 'very likely small' effect, # denotes 'likely moderate' effect

Table 5.6: Seasonal variation in normative strength, power and asymmetry

	Range of meaningful change*	July Testing	October Testing	January Testing	April Testing
Maximal Resistance (kg)	±31	321±65	330±65	343±66	351±67
Peak Power Combined (w)	±200	2336±515	2340±449	2422±493	2480±481
Average Power Combined (w)	±167	1910±394	1924±358	1968±369	2006±375
Velocity Max Combined (m/s)	±0.33	3.74±0.42	3.69±0.39	3.72±0.37	3.73±0.41
Force Max Combined (N)	±222	3253±696	3322±623	3387±647	3462±634
Absolute Difference Average (w)	±35	37.1±29.8	42.9±40.3	36.8±31.2	46.3±30.1
Percentage Difference Average (%)	±3.6	3.9±3.2	4.3±3.9	3.7±3.2	4.6±3.0

*Limits of meaningful change established from previously established test-retest reliability testing, calculated as 1.75 multiplied by the typical error across 3 consecutive tests.

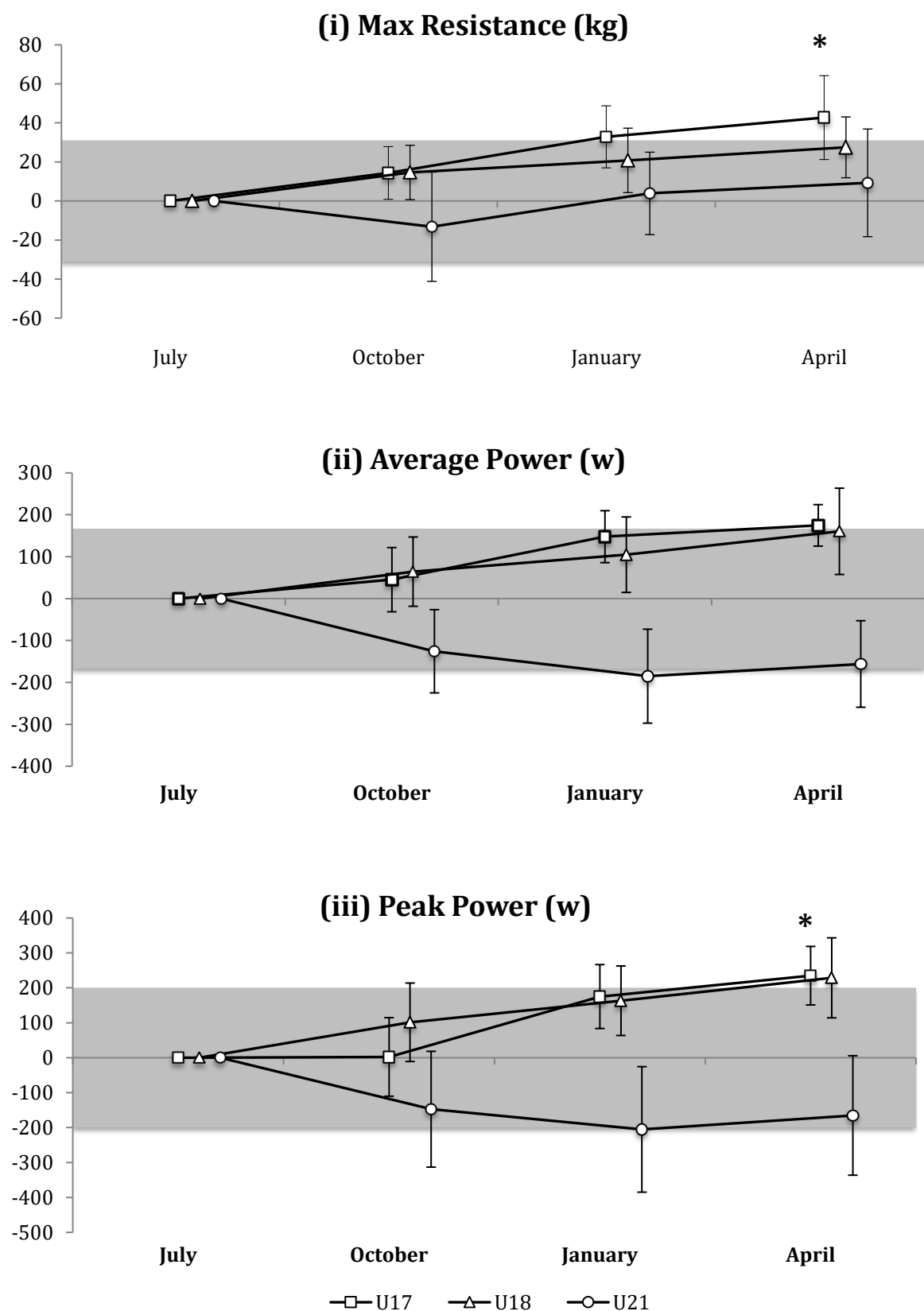


Figure 5.3: Difference (mean \pm 95% CI) in strength and power values of elite soccer players across 4 testing points over a soccer season dependent on playing squad.

Grey area highlights the range of meaningful change established for each variables played around zero. *-denotes 'likely' change from baseline for U17 squad

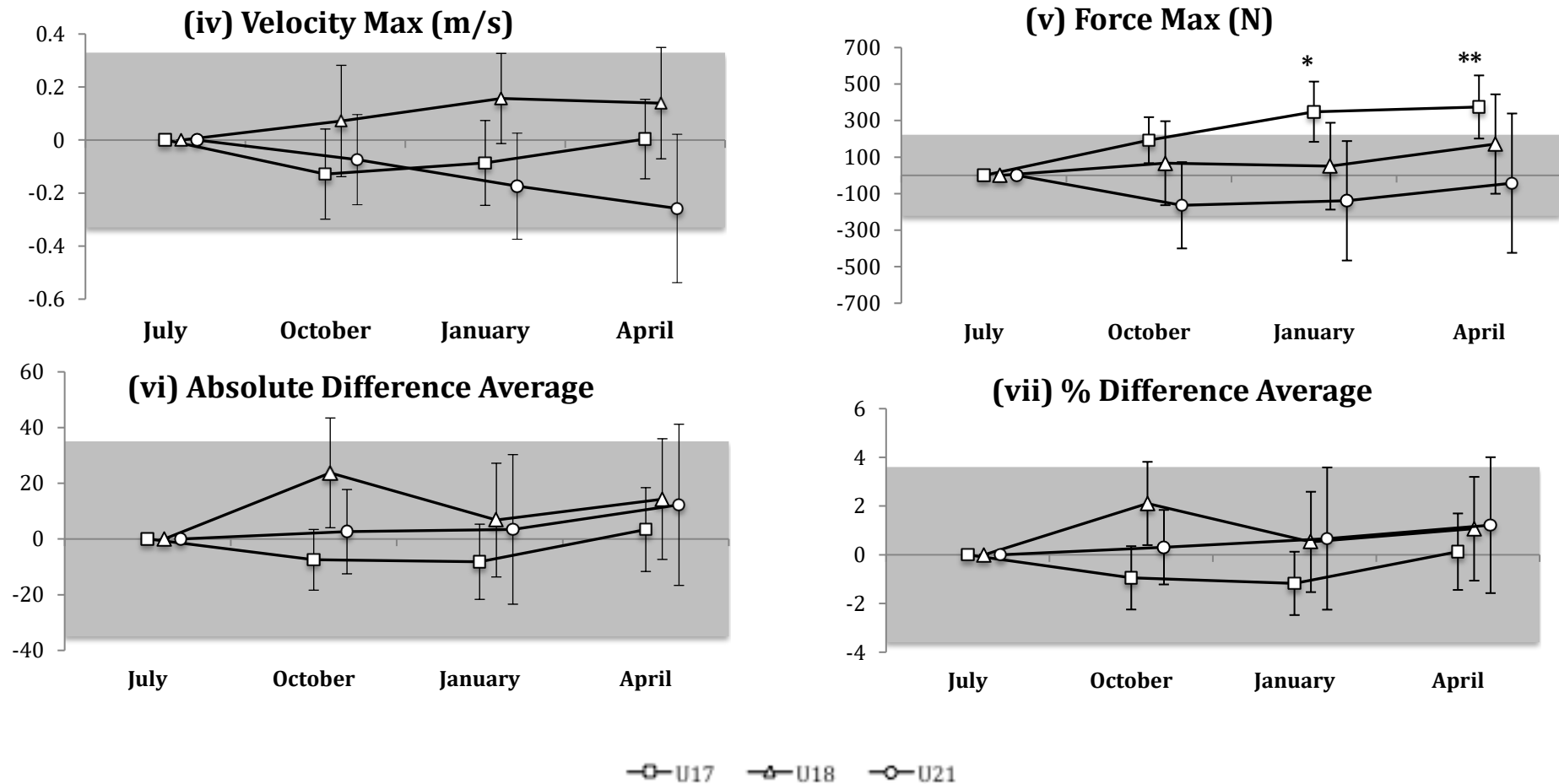


Figure 5.4: Difference (mean \pm 95% CI) in strength and power values of elite soccer players across 4 testing points over a soccer season testing dependent on playing squad.

Grey area highlights the range of non-significant change established for each variables placed around zero.*- denotes 'likely' change from baseline **- denotes 'very likely' change from baseline

5.4 Discussion

The primary aim of the current study was to establish typical characteristic lower limb strength, power and asymmetry values for elite soccer players using a pneumatic resistance seated leg press. The most notable finding was an average $4.3 \pm 4.1\%$ bilateral power asymmetries across all players. ‘Small’ superior strength and power values were found for Centre Backs and Strikers in multiple strength and power variables in comparison to the average of all players, but no clear effect was found for playing age group on strength and power values. Across a season, whilst no ‘likely’ substantial changes were seen in strength, power or asymmetry variables when comparing the average of all players and for U18 and U21 playing squads, ‘likely’ and ‘very likely’ increases in strength and power variables were seen for U17 squad at January and April testing time points.

To the author’s knowledge, the current study is the first to establish typical lower limb strength, power and asymmetry values for elite soccer players using a pneumatic resistance seated leg press. Typical average power asymmetry values established at $4.3 \pm 4.1\%$ are within the wide range of 1-10% from previous published research using isokinetic dynamometry and countermovement jumps in elite soccer players (Fousekis et al., 2010; Tournay-Chollet et al., 2005; Brito et al., 2010; Leatt et al., 1987; Impellizzeri et al., 2007; Menzel et al., 2013). More specifically, results from the current study are similar to Impellizzeri et al., (2007) who found 4-7% bilateral asymmetry values from isokinetic dynamometry testing and Menzel et al. (2013) who found average asymmetry values of 5.6% and 7.2% when assessing asymmetries of soccer players using both double leg jumps and isokinetic dynamometry, respectively. Utilising results found in Chapter 4 establishing reliability of measurements, the typical asymmetry value of $4.3 \pm 4.1\%$ found in the current study is close to the suggested asymmetry magnitude (4.4%) that warrants further testing and investigation to establish potential injury risk in soccer players. This finding combined with the large variation around the average value suggests that strength, power, and particularly asymmetry are highly variable between individuals and reinforce the importance of regular individual screening for potential bilateral lower limb strength and power deficits.

The current study found ‘likely small’ effect sizes for greater strength and power across multiple variables for Centre Backs and Strikers in comparison to the average

of all players. Goalkeepers, Full Backs, Centre Midfielders and Wide Midfielders were not clearly different to the average of all players. Findings are similar to previous position specific lower limb strength and power studies in soccer players that found Strikers (Boone et al., 2012; Wisloff et al., 1998; Tournay-Chollet et al., 2005), and Centre Backs (Boone et al., 2012; Arnason et al., 2004) to have higher jumps and peak concentric torque than other playing positions. Previous research has, however, also found higher strength and power values for Goalkeepers (Oberg, 1984; Arnason et al., 2004) in comparison to other playing positions, which was not clearly seen in the current study. Superior strength and power profiles of Centre Backs and Strikers can be expected due to the physical demands of their playing position. Strikers are required to complete more sprints (Bloomfield et al., 2007) per match than any other position, whilst both Strikers and Centre Backs are required to complete more jumps and headers (Reilly, 2003) per match than any other playing position. Both of these actions demand a high level of strength and power to complete successfully, and therefore enhanced lower limb strength and power profiles in these players is to be expected. In contrast, it has been suggested that strength differences between playing positions occur due to selection of players with existing physical qualities for certain positions rather than development of strength as a result of playing in that position (Reilly et al., 2000). Significant differences were seen in height and weight across the playing positions, and therefore it could be suggested that strength and power output should be have been corrected for bodyweight prior to comparison to account for this. When this supplementary analysis was completed, superior strength and power measurements for Strikers remained but superior strength and power measurements for Centre Backs was no longer apparent. Additionally, Goalkeepers were found to have ‘very likely moderate’ decreases in Maximal Resistance and Force Max in comparison to the average of the group, which were not previously seen. Whilst these differences in results for Centre Backs and Goalkeepers may highlight a masking effect of bodyweight on strength and power output, research has, in fact, found a weak relationship between movement velocity and body size, particularly in narrow weight ranges (Jaric, 2003). Additionally, as the aim of the current study was to establish muscle functional performance and not on field functional performance, it was not deemed appropriate to report all values bodyweight dependent in the current study.

When comparing between differing playing age groups, no significant differences were found in lower limb strength, power and asymmetry values. Although small effect sizes were seen for Average Power and Velocity Max in the U21 playing squad in comparison to the average of all players, no clear, consistent results were established. These findings conflict with previous research on lower limb strength and power across age groups in soccer that has found significant increases in lower limb strength and power with increasing chronological or training age (Leatt et al., 1987; Fousekis et al., 2010; Gur et al., 1999; Rochcongar et al., 1988). The difference in findings may be due to smaller variation in age range in the current study (16.8 years to 19.3 years) in comparison to previous research that spanned larger age ranges (17 years to 24 years for example). Indeed, Amato et al. (2001) found significant differences in peak torque between the youngest and oldest groups of soccer players (15 vs. 18.6 years) but not between the intermediate and oldest groups (16.9 vs. 18.6 years), with the latter comparison mirroring the age ranges in the current study. It should also be stated that the lack of differences between playing age groups might be a result of a type II error in the results due to the small sample sizes across the current study.

As no clear differences were seen for Goalkeepers, Full backs, Centre Midfielders and Wide Midfielders and no clear differences were seen across all age groups in comparison to the average of the group, it is appropriate to suggest that for these playing positions, comparison of future results in the applied environment can be made against the average benchmark of all players. However, regardless of playing squad, Centre Backs and Strikers would merit from position specific benchmark values for accurate evaluation of results.

Although no ‘likely’ substantial differences were found in lower limb strength, power and bilateral asymmetry across a season for all players, when seasonal variations were assessed dependent on playing squad, ‘likely’ and ‘very likely’ increases in multiple strength and power variables were found in the U17 playing age group in both January and April in comparison to baseline (July) testing. In contrast, no clear differences were seen at any time point for any variables for both U18 and U21 playing squads. Interestingly, these results reflect the conflicting previous literature in the area with some studies establishing clear increases in both jump performance and isokinetic peak torque values over a season in soccer players (Caldwell and

Peters, 2009; Lehnert et al., 2014; Eniseler et al., 2012) similar to the U17 playing squads, whilst others have failed to show any variation over a season, similar to the U21 playing squad. (Thomas and Reilly, 1979; Casajús, 2001; Silvestre et al., 2006). Across all three playing squads, no change was seen in bilateral asymmetry, which is comparable to the only other known study in the area (Eniseler et al., 2012). It could be suggested that as players progress into higher playing age groups, their training focus moves towards competition and away from development. Subsequently this may lead to higher number of lighter loading days found to occur around matches (Wrigley et al., 2012; Jeong et al., 2011) and therefore less opportunity for strength and power improvements. Practically, more pronounced increases in strength and power across a season would be expected for the U17 squad due this age group experiencing an increased training load over their previous season as they move from part time to full time training. In contrast, U18 and U21 squads are, in general, maintaining a similar training load to their previous season. It could be suggested that once this initial adaptation to increased load at U17 age group is achieved, further adaptations through age groups are less pronounced as increases in training load are less pronounced also.

Playing age group differences in seasonal strength and power adaptations could also be attributed to differences in players' maturation status at the time of testing. Therefore, superior strength gains would be expected in the older age groups which was not seen the current study. Differences in maturation status across the participants is more likely to be the cause of the large variation in change scores observed across the season in all three squads and reinforces the concept of high individual variation in response to a standardised training load stimulus. Although, with the youngest participant in the current study at 16.2 years, well above the average age of peak height velocity in European boys (Malina et al., 2004) and with the knowledge that youth soccer players generally tend to be advanced in their maturation status in comparison to general population (Malina, 2011), these effects of maturation on results in the current study may be minimal. That being said, the lack of maturation data to account for the variation in adaptation in the present study is a limitation and future research into longitudinal strength and power development using the seated leg press should investigate the role of maturation as a contributing factor.

Following the detailing of playing squad and playing position dependent typical characteristic values for soccer players, future research should be directed towards establishing associations between these values and injury incidence/burden in an attempt to establish greater understanding into the effect that various levels of strength, power and asymmetry have on injury risk.

5.4.1 Conclusion

The current study established typical characteristic lower limb strength, power and asymmetry values for elite soccer players using the Keiser Air420. Centre Backs and Strikers were found to have superior strength and power profiles in comparison to the average of all players and therefore warrant position specific benchmark values for accurate comparison. No clear differences were found in strength, power and bilateral asymmetry values when comparing between U17, U18 and U21 playing squads. However, when assessing variation in lower limb strength and power over a soccer season, the youngest age squads (U17) were found to show an increase in strength and power measures at January and April Testing, whilst the older age squads (U18 and U21 squads) maintained values from pre-season across all variables at all time points.

CHAPTER 6: ACUTE EFFECT OF PARTICIPATION IN A SOCCER MATCH ON LOWER LIMB STRENGTH, POWER AND ASYMMETRY

6.1 Introduction

Soccer is characterised as multidirectional intermittent high intensity exercise made up of lower intensity movements interspersed with short bouts of very intense activity (Stølen et al., 2005). Whilst running is the predominant activity, the sport involves repeated explosive efforts such as short sprints, rapid accelerations and decelerations, jumps, kicking and tackling (Cometti et al., 2001). Over a 90-minute soccer match, a player can cover anywhere between 8-13 km (Hawkins, 2004; Bradley et al., 2013; Barnes et al., 2014), of which ~7-12% is covered at high-intensity and 1-4% whilst sprinting (Di Salvo et al., 2010; Bush et al., 2015) with an explosive effort occurring on average every 30 seconds (Reilly, Bangsbo and Franks, 2000).

It is well recognised that prolonged multidirectional intermittent high intensity exercise like soccer will have a short term negative effect on lower limb strength and power (Spendiff et al., 2002) through a decrease in ability to recruit muscle fibres (Bangsbo, 1994), a decrease in muscle glycogen content (Krustrup et al., 2006; Bangsbo et al., 2007) and an accumulation of metabolites within the muscle fibres (Ament and Verkerke, 2009). Indeed, a decline in physical performance or physical fatigue, has been observed in soccer matches with studies establishing a decrease in total distance, high intensity distance and sprint distance covered in the second half of matches in comparison to the first (Di Salvo et al., 2009; Rampinini et al., 2009; Bradley et al., 2009; Nédélec et al., 2012; Ingebrigtsen et al., 2015). More specifically, Bradley et al. (2009) found that mean recovery time between high intensity running bouts increases towards the end of matches, with 28% and 17% longer recovery between high intensity and sprint bouts respectively in the final 15 minutes in comparison to the first 15 minutes. Moreover, as substitute players that enter the game in the second half complete 63% more sprint distance and 25% more high intensity distance than players who have completed the full game over the same time period (Mohr et al., 2003), decreases in workload can be isolated as due to fatigue rather than a natural variation in the intensity of a match.

Fatigue-induced decreases in lower limb absolute strength and power (Rahnama et al., 2003; Mair et al., 1996; Woods et al., 2004) have been associated with an increased risk of lower limb injury in soccer. Therefore, it is important to establish the magnitude of fatigue caused by soccer match participation to greater understand the injury risk that playing in a match carries.

Intervention studies have found anywhere between 7-25% decreases in eccentric and concentric knee flexion and extension peak torque through evaluation on isokinetic dynamometers at various speeds immediately following completion of soccer specific tasks (Andersson et al., 2008; Ascensao et al., 2008; Thorlund et al., 2009; Ali and Williams, 2013; Rahnama et al., 2003; Mercer et al., 2003; Robineau et al., 2012). Similarly, significant decreases in jump height (Oliver et al., 2008; Robineau et al., 2012; Romagnoli et al., 2016) and sprint performance (Ascensao et al., 2008; Krstrup; et al., 2010; Andersson et al., 2008) have also been seen when tested immediately post-match or soccer specific running protocols. However, conflicting research has found that concentric strength may not be significantly affected following completion of soccer specific running (Greig, 2008), and multiple studies have found that vertical jump performance did not decrease significantly when tested immediately post-match in comparison to baseline measurements (Krstrup et al., 2010; Hoffman et al., 2003; Thorlund et al., 2009). These results highlight that consensus across the literature is lacking.

The delayed onset of decrements in lower limb strength and power from exercise has been seen more consistently across the literature, with repeated research showing significant decreases of between 4-10% in vertical jump performance 24 hours after soccer-specific exercise (Fatouros et al., 2010; Andersson et al., 2008; Hoffman et al., 2003; Ispirlidis et al., 2008). Similarly, significant decreases in isokinetic peak torque (Andersson et al., 2008; Ascensao et al., 2008), sprint performance (Fatouros et al., 2010; Ascensao et al., 2008) and 1RM squat performance (Ispirlidis et al., 2008) have also been found 24 h, 48 h and up to 72 h after a soccer specific running protocol.

Increases in asymmetry following fatiguing exercise in have been reported in healthy individuals (Radzak et al., 2017), but the effect of soccer specific fatigue on between-limb strength and power asymmetry has not been extensively researched, despite its identification as a risk factor for injury in soccer (Croiser et al., 2008; McCall et al.,

2014; Opar et al., 2012). In the only paper known to the author, Rahnama et al. (2003) found no differences in left-right leg peak torque asymmetry preceding and immediately following a soccer specific treadmill protocol, despite finding significant decreases from baseline in absolute strength and power in both limbs. However, as the treadmill protocol in the study did not include any change of direction or soccer specific movements, it is possible that potential mechanisms contributing to fatigue might not have been impacted. Further research is needed to validate these findings as well as evaluate the delayed effects of fatiguing exercise on lower limb strength and power asymmetry.

Despite the capability of the Keiser Air420 bilateral seated leg press to measure individual leg power values and left-right leg power asymmetries, no research has been published establishing the effect of participation in a competitive soccer match on strength, power and asymmetry using the equipment.

Therefore the current study aims to establish the immediate and delayed effects of participation in competitive soccer matches on lower limb strength, power and bilateral asymmetry of elite professional soccer players assessed using the Keiser Air420 seated leg press.

6.2 Methods

A total of 19 elite soccer players (Age: 19.0 ± 1.0 y, Height: 179.8 ± 7.0 cm, Weight: 73.6 ± 8.0 kg) volunteered to participate in the study. All participants were playing academy standard soccer full time for the same premier league football club and were either training within the U21 playing squad (1 tier below the first team) or the Scholar Squad (2 tiers below the first team). Inclusion criteria were that they were injury free (defined as a 'time loss injury', classified in a consensus statement on injuries within soccer (Fuller et al., 2006)) at the testing period and had not sustained a serious injury (unable to participate in full squad training for > 8 weeks) in the 6 months preceding the testing period.

Prior to any testing, participants were measured for height and weight. Training loads completed following baseline testing on the day prior to the match and load completed during the match were established through GPS monitoring (Statsports Viper, Statsports Technologies Ltd., N.Ireland).

Participants undertook the progressive resistance leg press test on three separate occasions around a competitive soccer match. Baseline measurements were taken on the day preceding the match (27 ± 0.9 h pre match-PRE) with repeated testing taken immediately post-match (0.4 ± 0.1 h post-match-POST) and on the day after the match (19.6 ± 1.3 h post-match-24 h POST). To ensure minimum time between the conclusion of the match and immediate post-match testing, a maximum of 4 participants were tested around any game and all tests were completed around multiple matches over the course of a season.

Prior to PRE testing and 24 h POST testing, participants completed a 5-minute standardised warm up at approximately 60-75 watts on a cycle ergometer (Keiser M3+, Keiser Corporation, California) followed by ten controlled bodyweight squats and 3 sub maximal countermovement jumps. The standardised warm up was not completed prior to POST testing in an attempt to get tests completed as soon as possible post-match.

On all testing occasions the incremental resistance leg press test was completed as described in Chapter 3: General Methodology following the testing procedure outlined in Table 3.1.

Peak Power (the highest power output from each test for each leg) and Average Power (the average of all power outputs for each leg) were recorded for each test. Velocity Max and Force Max are calculated by creating a line of best fit against the velocity-force values calculated on each repetition for each leg and then extrapolating back to 0 kg resistance and 0 m/s velocity for Velocity Max and Force Max respectively as shown in Figure 3.3.

Peak Power Combined, Average Power Combined, Force Max Combined and Velocity Max Combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

Bilateral power asymmetry variables for the current chapter were calculated using average power variables through the Percentage Differences calculation method, described in full in Chapter 3: General Methodology.

Bilateral power asymmetry has been calculated to denote a positive number regardless of left or right leg power dominance. This asymmetry calculation method has been taken to give a true reflection of the magnitude of bilateral asymmetry amongst the sample as when asymmetry values with left or right directional notation, individuals with left dominant asymmetries may cancel out individuals with right dominant asymmetries resulting in an incorrect and uninformative average value.

6.2.1 Statistical Analysis

Data was analysed using Microsoft Excel (Microsoft, Redmond, WA) and statistical package SPSS (Version 21.0; Chicago, IL) and all data are presented as mean \pm standard deviation. T-tests were calculated for a comparison between all time points and magnitude based inferences were derived (Batterham and Hopkins, 2006). Limits of meaningful change established through test-retest reliability testing were used to set thresholds for a practically important effect and were calculated as 1.75 multiplied by the typical error across 3 consecutive tests (Hopkins, 2000). Using these, along with results of t-tests, likelihoods of effect magnitudes were calculated and adjusted for dependent on total distance and high intensity distance covered during the soccer match in a customized Excel spreadsheet (Hopkins, 2017). An effect was deemed unclear if the likelihoods that the effect was substantially positive and negative were both $\geq 5\%$. Otherwise, the effect was deemed clear and was qualified with a probabilistic term using the following scale: 25-75% possible; 75-95% likely; 95-99.5% very likely; $> 99.5\%$ most likely. That is, only at least 'likely' effects were considered meaningful. Risk of injury banding for % Difference Ave of $< 4.4\%$: Low Risk, 4.4-11.2%: Moderate Risk and $> 11.2\%$: High Risk established through previous reliability testing and research into asymmetry and injury incidence (Orchard et al., 1997) were used to further evaluate changes in bilateral asymmetry across tests.

6.3 Results

Despite decreases in values at POST and 24 h POST testing in comparison to PRE testing for all strength and power variables, magnitude-based inference analysis did not reveal any clear changes from PRE testing for all variables (Table 6.1). Analysis was also completed after the removal of a clear outlier (> 2 SD away from mean response) identified from Figure 6.1 (iii) and a 'possible' decrease in Peak Power

Combined at 24 h POST testing was found with no other differences seen for any other results.

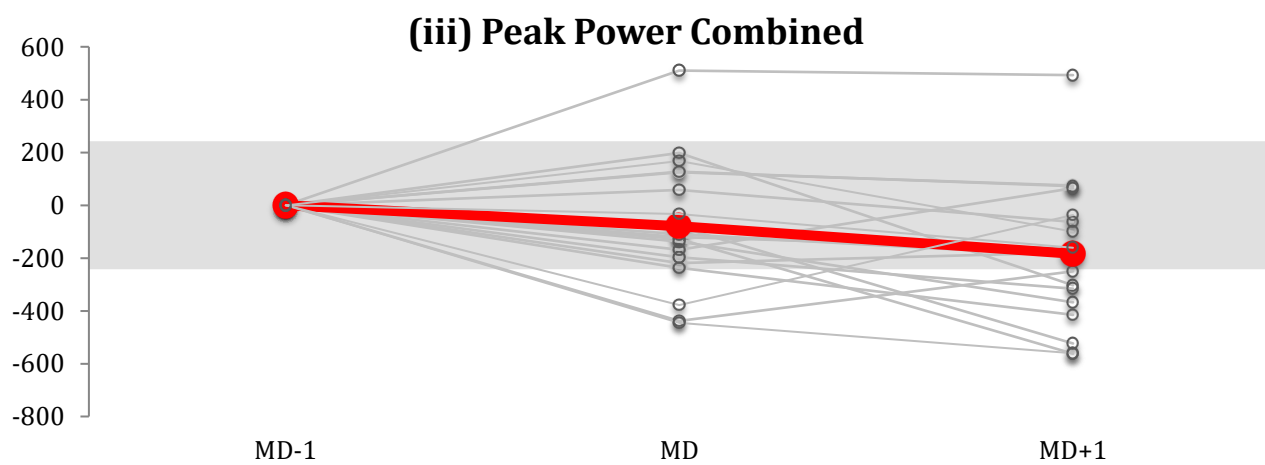
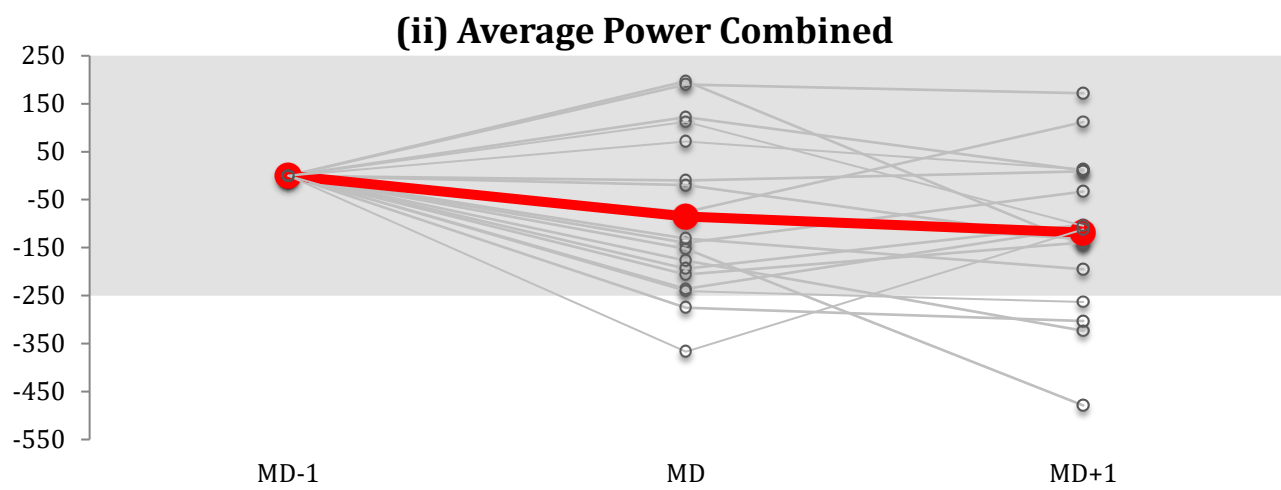
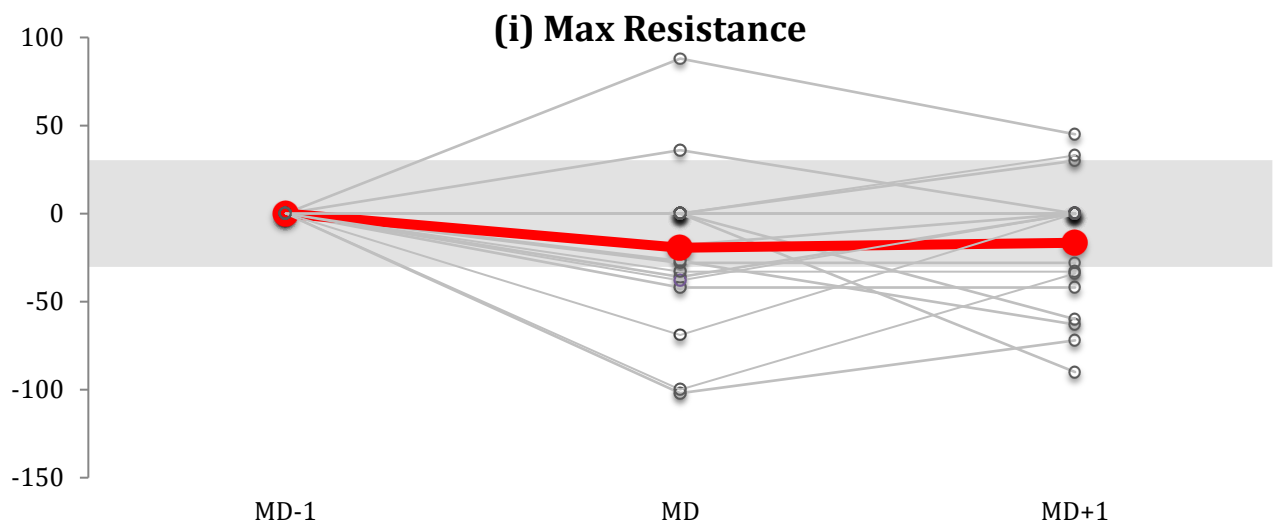
Table 6.1: Strength, power and asymmetry values (mean \pm SD) for 3 testing points around a soccer match

	PRE Testing	POST Testing	24 h POST Testing
Maximal Resistance (kg)	405 \pm 74	384 \pm 81	386 \pm 75
Peak Power Combined (w)	2665 \pm 567	2553 \pm 508	2444 \pm 494
Average Power Combined (w)	2079 \pm 403	1979 \pm 379	1944 \pm 370
Velocity Max Combined (m/s)	3.65 \pm 0.41	3.53 \pm 0.45	3.58 \pm 0.55
Force Max Combined (N)	3787 \pm 842	3752 \pm 687	3712 \pm 1144
% Difference Average	4.6 \pm 3.5	6.3 \pm 4.8	5.0 \pm 3.5

For % Difference Average, although no differences were seen at any time point (Figure 6.2), utilising the risk bandings calculated in previous smallest worthwhile change testing, asymmetry values increased to a higher risk banding for 5/19 participants between PRE to POST and also between PRE-24 h POST testing (Table 6.2).

Table 6.2: Individual change in asymmetry risk between tests of 19 participants

	% Difference Average	
	PRE to POST	PRE to 24 h POST
Lower Risk Banding to Higher Risk Banding	5	5
Unchanged	10	11
Higher Risk Banding to Lower Risk Banding	4	3



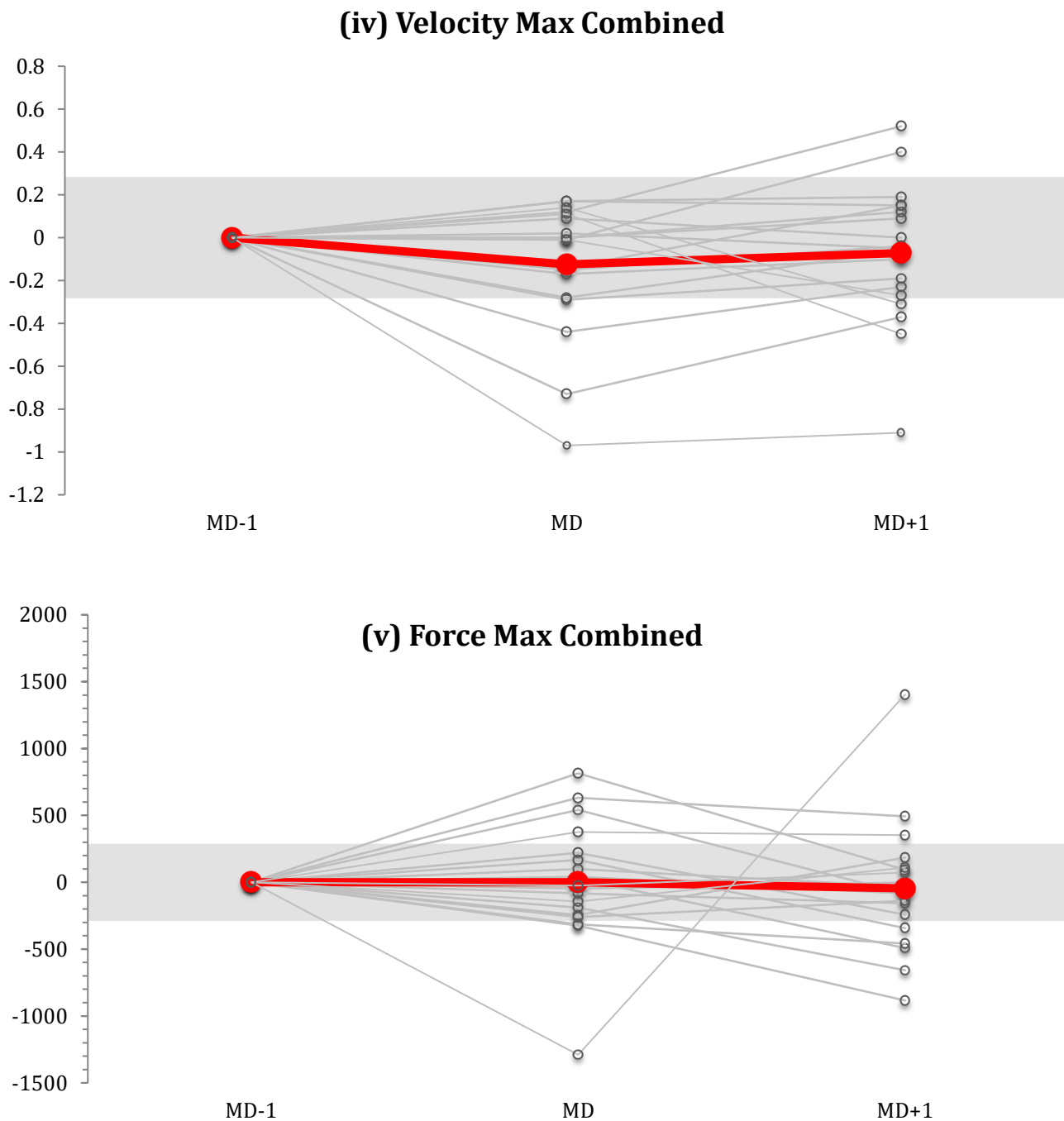


Figure 6.1: Mean and individual change from baseline (MD-1) testing following participation in a soccer match for various strength and power values in elite soccer players.

Grey areas highlight the limits of meaningful change* established for each variable placed around zero. *Limits of meaningful change established from previously established test-retest reliability testing- calculated as 1.75 multiplied by the typical error across 3 consecutive tests.

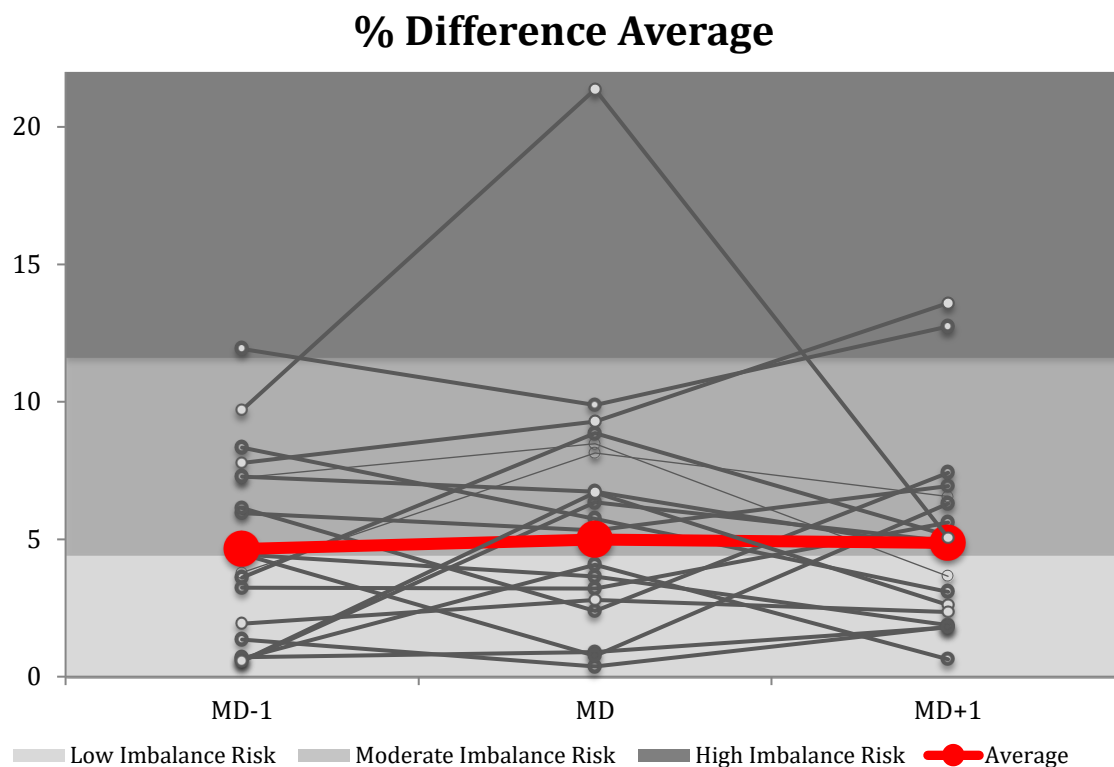


Figure 6.2: Mean and individual bilateral asymmetry values for elite soccer players from 3 repeated tests around participants in a soccer match.

Grey areas highlight the ranges of potential injury risk from bilateral asymmetry. Ranges were calculated from minimum values from published literature in combination with typical error values calculated in Chapter 4.

6.4 Discussion

The aim of the current study was to investigate the effect of participation in a competitive soccer match on lower limb strength, power and bilateral asymmetry assessed through seated leg press. No clear differences were seen across any parameters immediately post-match or at 24 h POST testing in comparison to baseline measurements. Although asymmetry values for 5/19 participants increased to a higher injury risk banding at both testing points, no ‘clear’ differences in average power bilateral asymmetry were seen at POST or 24 h POST testing in comparison to PRE testing values.

Findings from the current study suggest that participation in a competitive soccer match does not substantially decrease maximal strength, average power or peak power immediately post-match. The current findings agree with previous literature assessing jump height (Krustrup et al., 2010; Hoffman et al., 2003; Thorlund et al.,

2009) immediately after a soccer match that did not find any decrease in performance and suggest that acute fatigue accumulation around a soccer match may be more clearly identified following intense periods of play within a match as opposed to following its conclusion (Krustrup et al., 2006; Bradley et al., 2010). Results from the current study, do, however, contrast with a handful of studies that have found significant decreases in jump height (Andersson et al., 2008; Romagnoli et al., 2016) and concentric knee flexion and extension (Ascensao et al., 2008; Thorlund et al., 2009) immediately following a competitive soccer match. The current study also found that, on average across all participants, playing a soccer match had no clear effect on lower limb bilateral power asymmetries immediately post-match. Indeed, Percentage Difference values across the current study (3.5-5.2%) were very similar to normative values established in Chapter 5 (4.3%) and reinforce that typical bilateral asymmetry values are low in this group of elite soccer players. Results from the current study agree very well with Rahnema et al. (2003) who also did not find any differences in bilateral peak torque asymmetries preceding and immediately following soccer specific treadmill running.

The lack of consensus across the literature with regards to lower limb strength and power immediately post soccer match highlights potential individual differences in response to a stimulus seen across sport. This is strongly reflected in the current study (**Figure 6.1**), which saw a range of both improvements and decrements in comparison to baseline measurements across all parameters at POST testing. However, as comparison to a control group was not possible in the current study, it is difficult to establish whether differences seen are due to true inter-individual differences in response to match play or simply natural within-subject biological variation (Atkinson and Batterham, 2015). Indeed, 5 out of 19 (~26%) players moved to a higher risk banding for bilateral asymmetry at POST testing in comparison to baseline suggesting that match participation may increase asymmetry for certain individuals. However as the standard deviation of change in asymmetry between PRE and POST testing was very similar to that found in reliability testing in Chapter 4, individuals that increased might just be part of the natural biological variation of the group.

The current study also did not find any ‘likely’ differences in lower limb strength, power or bilateral asymmetry at 24 hours post-match in comparison to pre-match measurements either. However, when the analysis was repeated with a clear outlier

removed, 'possible' decreases in Peak Power Combined were seen at 24 h POST in comparison to PRE testing. This latter finding supports Hoffman et al. (2003) who found significant decreases in countermovement jump peak power 24 hours post-match despite establishing no differences in performance immediately post-match. Although assessed using a different measurement tool, the ~8% decrease in peak power seen in the current study is well aligned with the 4-10% decreases seen in vertical jump performance in previous literature 24 hours after soccer-specific exercise (Fatouros et al., 2010; Andersson et al., 2008; Ispirlidis et al., 2008). This delayed decrease in power output is largely attributed to exercise induced muscle damage and inflammation (Fatouros et al., 2010; Ascensao et al., 2008) and subsequent decrease in muscular force (Raastad and Hallén, 2000) from repeated high force, high intensity muscle actions often seen in soccer matches (Andersson et al., 2008).

Practically, results from the current study suggest that, despite a lack of decrease in physical performance immediately post-match, physical performance 24 h post-match may be negatively affected for certain individuals. Although clear decreases in Peak Power were not established across the group, the standard deviation of change in Peak Power 24 h POST in comparison to baseline was notably higher than the standard deviation of change in peak power at previous completed reliability testing (260 W SD vs. 161 W SD), and 8/19 participants did show peak power decreases outside of the limits of meaningful change at 24 h POST testing. These findings suggest that individual differences in response to match play may be evident 24 h following a match and that it would be appropriate to individually screen players' strength and power capabilities relative to their baseline values to evaluate their ability to train. As the current study did not complete any later assessments than 24 h post-match, to establish a comprehensive overview of fatigue induced decreases in performance, future research should be aimed at establishing the prolonged effect of participation in a soccer match on lower limb strength, power and bilateral asymmetry values as well as establishing the effect that potential match induced changes in lower limb strength, power and bilateral asymmetry have on soccer performance and lower limb injury risk. This is particularly important considering the current requirement, at points within the season, for soccer players to play 2 competitive matches within < 72 h. Clear consensus and establishment of the prolonged effects of match participation on

lower limb strength, power and bilateral asymmetry in soccer would be greatly beneficial to the practitioner for appropriate planning of training programmes and fixture scheduling that minimises risk of injury whilst also maximising performance.

Results in the current study did not show a clear decrease in performance 24 h post match, which has been clearly demonstrated in previous research. Therefore, it could be suggested that the current testing protocol may not adequately sensitive to evaluate the effect of match-induced fatigue on lower limb strength and power or that the sample size used in the current study was not large enough to identify significant decrements in performance. Contrarily, these findings may suggest that temporary fatigue following periods of high intensity work during match play established by Bradley et al. (2009) is more significant than accumulated fatigue post-match. Future research should aim to replicate the current study with a larger cohort and with inclusion of a battery of lower limb strength and power testing protocols to establish whether seated leg press testing accurately identifies fatigue induced decreases in lower limb performance that occur around match play.

6.4.1 Conclusion

To conclude, the current study did not find any differences in lower limb strength and power assessed through seated leg press immediately following or 24 hour after completing a competitive soccer match. However, excluding a clear outlier in the dataset, 'possible' decreases in Peak Power were observed 24 h post-match in line with previous research. No differences were seen at any time point for bilateral asymmetry variables, however ~26% of players experienced an increase in asymmetry values to a higher injury risk banding at both POST and 24 h POST, and so these player' workloads and their responses to workloads should be carefully monitored and managed. Overall, these results highlight the high individual differences in physical performance following soccer match play.

CHAPTER 7: INVESTIGATION INTO THE ASSOCIATION BETWEEN LOWER LIMB STRENGTH, POWER AND ASYMMETRY WITH INJURY INCIDENCE AND BURDEN IN ELITE SOCCER PLAYERS

7.1 Introduction

Due to high physical demands on the body and repeated exposure to contact at high velocity, the risk of injury within elite soccer is relatively high (Waldén, Hagglund and Ekstrand, 2005), with injury incidence rates ranging from 3.4 to 5.9 per 1000 training hours and 25.9 to 34.8 per 1000 match hours (Hawkins and Fuller, 1999; Ekstrand et al., 2004a; Ekstrand et al., 2011; Arnason et al., 2004). A professional soccer player can expect to incur, on average, two injuries that result in time-loss from full team training or match selection per season (Ekstrand et al., 2011a). Muscle injuries are the most common cause of time lost through injury, making up anywhere between 20-41% of all injuries (Ekstrand et al., 2011a; Ekstrand et al., 2011b; Hagglund et al., 2013; Hawkins and Fuller, 1999).

Whilst it is widely accepted that the cause of injury is multifactorial (Hagglund et al., 2013; Opar et al., 2012; Arnason et al., 2004; Ekstrand et al., 2011b), lower limb muscle strength, power and bilateral asymmetry has been consistently identified as an important modifiable risk factor (Burkett et al., 1970; Orchard et al., 1997; Croisier et al., 2004; Henderson et al., 2010; van Beijsterveldt et al., 2013). Specifically, within soccer, low absolute muscular strength has been consistently linked with an increase in both muscle and non-contact injury incidence (Engebretsen et al., 2010; Fousekis et al., 2011; Soderman et al., 2001; Timmins et al., 2016; Ekstrand and Gillquist, 1983). Engebretsen et al. (2010) found that soccer players with adductor weakness had a four times higher risk of injury, whilst Timmins et al. (2016) found low absolute hamstring strength to be the main risk factor for subsequent hamstring injury in soccer players. Similarly, it has also consistently been shown that increasing strength through sustained resistance training can reduce injury risk (Fleck and Falkel, 1986; Heidt et al., 2000; Askling et al., 2003; Heiser et al., 1984).

Conversely, when assessing power (defined as the ability to move a resistance at speed), elite soccer players with superior power outputs have been found to be at a

higher risk of injury (Henderson et al., 2010; Engebretsen et al., 2010). Indeed, Henderson et al. (2010) established a 1.5 times increase in hamstring injury risk for every extra 1 cm jumped on a squat jump in Premier League soccer players. Similarly, Engebretsen et al. (2010) reported 40 m sprint time to be a significant risk factor for groin injury in soccer, with the suggestion that an individual's inability to control their powerful actions may increase their risk of injury (Henderson et al., 2010)

Bilateral strength and power asymmetries have also been shown to increase injury risk in soccer players (Fousekis et al., 2010; Croisier et al., 2008) with practitioners reporting it as the third most important non-contact risk factor for injury (McCall et al., 2014). Indeed, Croisier et al. (2008) found that soccer players with unaddressed bilateral asymmetries had 4.7 times greater risk of hamstring injury. Both Fousekis et al. (2010) and Knapik et al. (1991) found that players with eccentric hamstring or quadriceps bilateral asymmetries of greater than 15% were at a significantly greater risk of muscle strain than those without.

Whilst it has been shown across the literature that lower limb strength, power and asymmetry all have an important role to play in injury risk in soccer, unfortunately, the vast majority of research investigating these three parameters has been completed using maximal voluntary contractions of knee flexors and extensors via an isokinetic dynamometer. It has been suggested that isolated independent maximal contractions of the hamstring and quadriceps muscles are not representative of the functional actions seen on a soccer field (Newton et al., 2006), and so further research is needed to identify the role of lower limb strength, power and asymmetry on injury risk assessed through more functional/soccer specific movements. Indeed, whilst comparing strength and power asymmetry methods in team sports athletes, Jones and Bampouras (2010) found no significant relationship between lower limb bilateral asymmetry values measured using isokinetic dynamometry and a unilateral leg press, reinforcing the need to utilise tests that assess the type of actions most used in their sport in order to get the most valid results.

Previous chapters in the current thesis have established the reliability, limits of meaningful change and typical characteristic values for soccer players using the Keiser Air420 (A420) seated leg press. However, for optimal evaluation of any tests

performed in the applied environment, association of testing results with injury risk in soccer is needed.

Therefore, the aim of the current study is to investigate the association between bilateral seated leg press strength, power and asymmetry values measured in pre-season and subsequent injury incidence and burden over the following season.

7.2 Methodology

A total of 61 players (17.9 ± 1.4 yrs, 70.3 ± 8.4 kg, 178 ± 7 cm, $9.5 \pm 1.8\%$ body fat) over the course of three seasons volunteered to participate in the study. All participants were playing full time academy standard soccer at the same premier league football club and were either training within the U21 Squad (1 tier below the First Team) or the Scholar Squad (2 tiers below the First Team). Criteria for inclusion within the study were that they were fit to participate in full training prior to their seated leg press test, that they had full injury incidence reporting for the subsequent season, full training and match exposure for the subsequent season and that they were familiarised to the testing protocol (had completed the testing protocol on at least three separate occasions to their assessment test).

Participants undertook an incremental resistance leg press in July at the beginning of a period of pre-season training. All tests occurred at the same time of day, following a day consisting of minimal physical stimulus (< 4000 m total distance, < 50 m high intensity distance and < 5 minutes above 85% max heart rate) established through GPS monitoring (Statsports Viper, Statsports Technologies Ltd., N.Ireland).

Following this, each participant's on-field training and match exposure across the following season was logged and collated. Over the data collection period of three seasons, 104 participant entries comprising of pre-season testing, full season-long training and match exposure and record of injury incidence were collected with multiple participants (1 season entry: 27 participants, 2 seasons entries: 25 participants, 3 seasons entries: 9 participants) completing entries on more than 1 season; this was accounted for in the analysis.

For all participants, the incremental resistance leg press test was completed as described in Chapter 3: General Methodology following the testing procedure outlined in Table 3.1.

Peak Power (the highest power output from each test for each leg) and Average Power (the average of all power outputs for each leg) were recorded for each test. Velocity Max and Force Max are calculated by creating a line of best fit against the velocity-force values calculated on each repetition for each leg and then extrapolating back to 0 kg resistance and 0 m/s velocity for Velocity Max and Force Max respectively as shown in Figure 3.3. Peak Power Combined, Average Power Combined, Force Max Combined and Velocity Max Combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

Bilateral power asymmetry variables were calculated using average and peak power variables through the Percentage Differences calculation method which is described in full in Chapter 3: General Methodology.

Both power asymmetry variables have been calculated to denote a positive number regardless of left or right leg power dominance. This asymmetry calculation method has been taken to give a true reflection of the magnitude of bilateral asymmetry amongst the sample so individuals with ‘negative’ dominant asymmetries do not cancel out individuals with ‘positive’ dominant asymmetries which may result in an inappropriate and uninformative average values.

The number of minutes trained and played in competitive matches were logged daily for each individual by a member of the sports medical team using Microsoft Excel (Microsoft, Redmond, WA) and totalled at the end of the season. Similarly injury incidence was logged in detail through-out the season using a bespoke online portal (Yatron, Tonic Designs, London, UK) by a member of the sports medical team and included in the study if a player was subjected to a time-loss injury as classified in a consensus statement on injuries within soccer (Fuller et al., 2006). Injury burden, or days out through injury, was counted from the day following the injury incidence until the player resumed full, unrestricted training with the squad. ‘Early recurrent’ injuries defined as injuries of the same type and at the same site as the original injury within 2 months of return to full participation in training (Fuller et al, 2006) were excluded from study in an attempt to limit the affect of recent previous injury on incidence and burden rates.

As well as looking at incidence and burden from all injuries over a season, a sub-set of ‘relevant’ training and match injuries were selected for investigation within the study also. ‘Relevant’ injuries were defined as:

- Any lower body non-contact muscle, ligament or tendon injuries
- Any lumbar overuse stress related injuries

This criterion was selected as it was decided that the vast majority of upper body injuries and all contact injuries were unlikely to be directly associated with the risk factors being investigated similar to previous research in the area (McCall et al., 2014; Gabbett, 2010).

7.2.1 Statistical Analysis

Training and match injury incidence rates were reported as the number of injuries per 1000 hours of training and match exposure. Univariate associations between A420 strength, power and bilateral asymmetry risk factors and injury incidence were investigated using Poisson regression. Overdispersion was controlled for using a Pearson χ^2 scaling parameter (McCullagh and Nelder, 1989). The regression analyses were performed using Generalised Estimating Equations (GEE) in IBM SPSS Statistics for Windows (Version 21, Armonk, New York, NY, USA). The GEE model was chosen for its ability to handle repeated measures (i.e., players involved in multiple seasons). Incidence rate ratios and associated 95% confidence intervals were evaluated relative to a two-fold standard deviation (2SD) increase in the risk factor (i.e., a typically low to typically high value) (Hopkins et al., 2009). Magnitude based inferences were also used to provide an interpretation of the real-world relevance of the outcome values. The smallest worthwhile increase in risk for injuries was a rate ratio of 1.1 and the smallest worthwhile decrease in risk for injuries was a rate ratio of 0.9. An effect was deemed unclear if the chance that the true value was beneficial was >25% with the odds of benefit relative to odds of harm (odds ratio) of <66. Otherwise, the effect was deemed clear and was qualified with probabilistic term using the following scale: < 0.5%, most unlikely; 0.5-5% very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely, >99.5%, most likely.

7.3 Results

7.3.1 Injury frequency

In total, 199 time loss injuries were reported over three seasons. Of these, 57% occurred in training and 43% in matches (Table 7.1). The most common sites for injury were ankle (26%), knee (16%), quadriceps (11%) and hamstring (10%). A subset of 98 injuries were classified as ‘relevant’ injuries, with most common sites for ‘relevant’ injury being hamstring (18%), ankle (16%), hip flexor/groin (16%) and knee (15%).

7.3.2 Lower limb strength, power and asymmetry and injury incidence

When accounting for exposure, the incidence rate for all injuries was 3.5 times higher during match play in comparison to training (20.2 vs. 5.6 per 1000 h exposure, Table 7.2) and the injury burden was 4.5 times higher during match play in comparison to training (410 vs. 89 days lost per 1000 h exposure, Table 7.2).

Due to narrowing of injury definition, injury incidence and burden was lower for ‘relevant’ injuries, with injury incidence and injury burden ~3 times higher during match play in comparison to training (8.9 vs. 3.0 injuries and 154 vs. 50 days per 1000 h exposure respectively, Table 7.3).

Mean of days lost through injury was 34 for all injuries and 16 for relevant injuries whilst median of days lost was 16 for all injuries and 6 for relevant injuries.

When assessing lower limb strength, power and asymmetry risk factors relative to all injuries, a ‘likely harmful’ effect was found for Force Max Combined, with a 21% increase in injury risk for every 2SD (1353 N) increase. Additionally, a ‘possibly beneficial’ effect was found for % Difference Average asymmetry, with a 15% decrease in injury risk for every 2SD (7.3%) increase. Effects between all other strength, power and asymmetry variables and injury incidence were deemed unclear (Figure 7.1).

When assessing lower limb strength, power and bilateral asymmetry risk factors relative to relevant injuries, ‘possible beneficial’ effects were found for Velocity Max Combined, with a 22% decrease in injury risk for every 2SD (0.98 m/s) increase.

Effects for all other strength, power and asymmetry variables were deemed unclear (Figure 7.2).

Table 7.1: Training and match injury frequency and site of injury for all and relevant injuries

	All Injuries	Relevant Injuries
Back	7	7
Knee	31	15
Ankle	51	16
Hip Flexor/Groin	17	16
Adductor	7	7
Gluteal	1	1
Hamstring	19	18
Quadricep	22	11
Calf/Achilles	7	3
Foot/Toe	13	4
Head	9	0
Chest/Shoulder	9	0
Wrist/Elbow	6	0
Total Injuries	199	98
Total Training Injuries	113 (57%)	60 (61%)
Total Match Injuries	86 (43%)	38 (39%)

Table 7.2: Injury incidence and injury burden per 1000 h exposure over 3 consecutive seasons for all injuries

	Combined	Training	Match
No of Injuries	199	113 (57%)	86 (43%)
Exposure (hours)	24509	20245	4264
Injury Rate per 1000 h	8.1 (6.8-9.6)	5.6 (4.5-7.0)	20.2 (15.6-26.0)
Days lost due to Injury	3549	1800	1749
Injury Burden per 1000 h	145 (103-203)	89 (60-132)	410 (264-636)

Table 7.3: Injury incidence and injury burden per 1000 h exposure over 3 consecutive seasons for 'relevant' injuries

	Combined	Train	Match
No of Injuries	98	60 (61%)	38 (39%)
Exposure (hours)	24509	20245	4264
Injury Rate per 1000 h	4.0 (3.2-4.9)	3.0 (2.2-4.0)	8.9 (6.2-12.8)
Days lost due to Injury	1675	1017	658
Injury Burden per 1000 h	68 (38-124)	50 (27-93)	154 (79-303)

7.3.3 Lower limb strength, power and asymmetry and injury burden

When assessing lower limb strength, power and asymmetry risk factors relative to injury burden from all injuries, ‘very likely’ harmful effects were seen for Peak Power Combined, Average Power Combined and Force Max Combined, with 185%, 141% and 128% increase in injury burden for every 2SD increases respectively. ‘Likely’ harmful effects were seen for Maximal Resistance, with a 72% increase in injury risk for every 2SD increase and ‘very likely’ beneficial effects were seen for % Difference

Average asymmetry, with a 38% decrease in injury burden for every 2SD increase in asymmetry (Figure 7.3).

When assessing lower limb strength, power and bilateral asymmetry risk factors relative to injury burden from relevant injuries, ‘likely’ harmful effects were seen for Maximal Resistance, Peak Power Combined, Average Power Combined and Force Max Combined, with 114%, 309%, 194% and 198% increases in injury burden for every 2SD increase, respectively. Effects were deemed unclear between relevant injury burden and Velocity Max Combined, % Difference Average asymmetry, and % Difference Peak asymmetry (Figure 7.4).

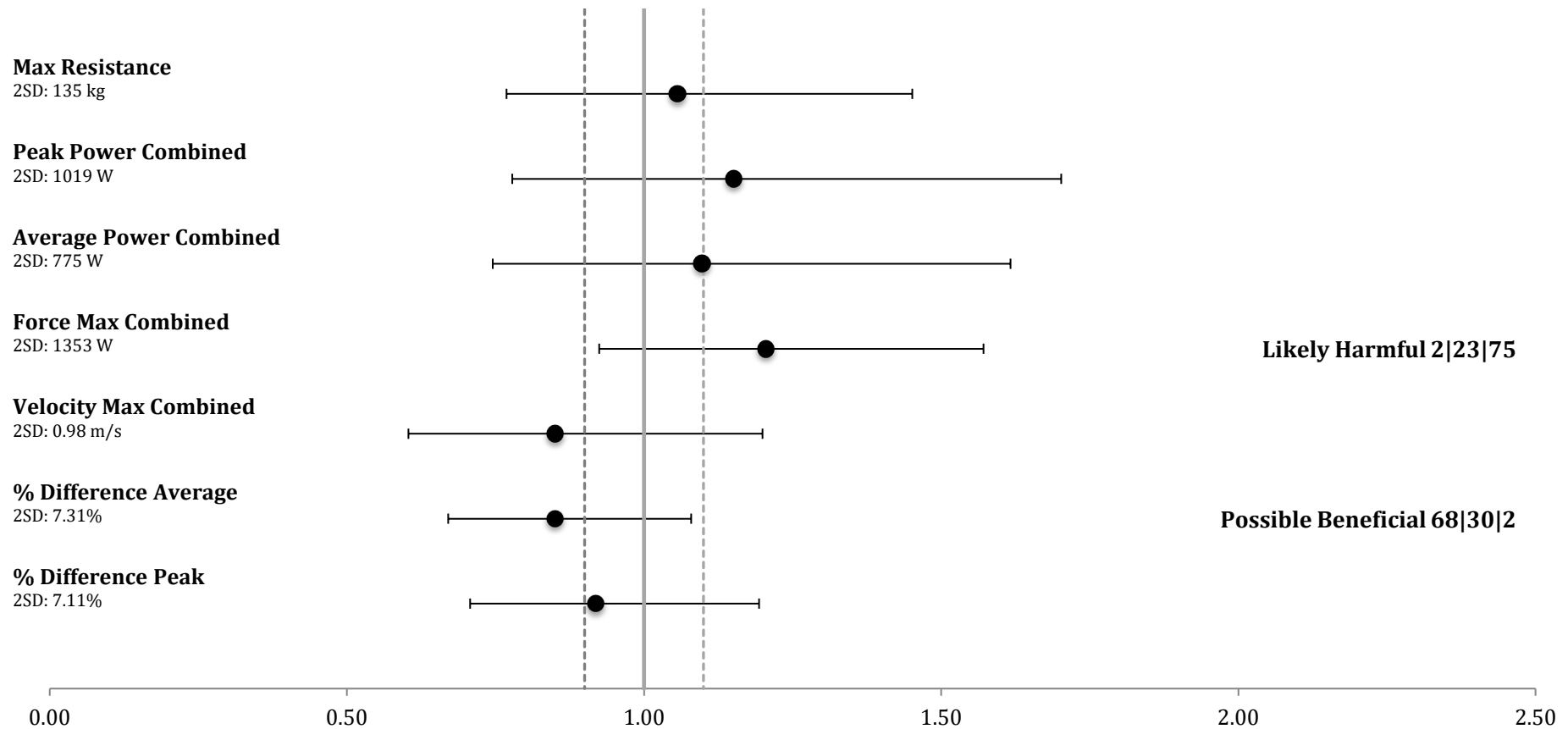


Figure 7.1: Risk ratio of variables for various lower limb strength, power and asymmetry variables and lower limb injury risk for all injuries.

Dashed lines represent the boundaries of smallest worthwhile decrease/increase in risk of injury

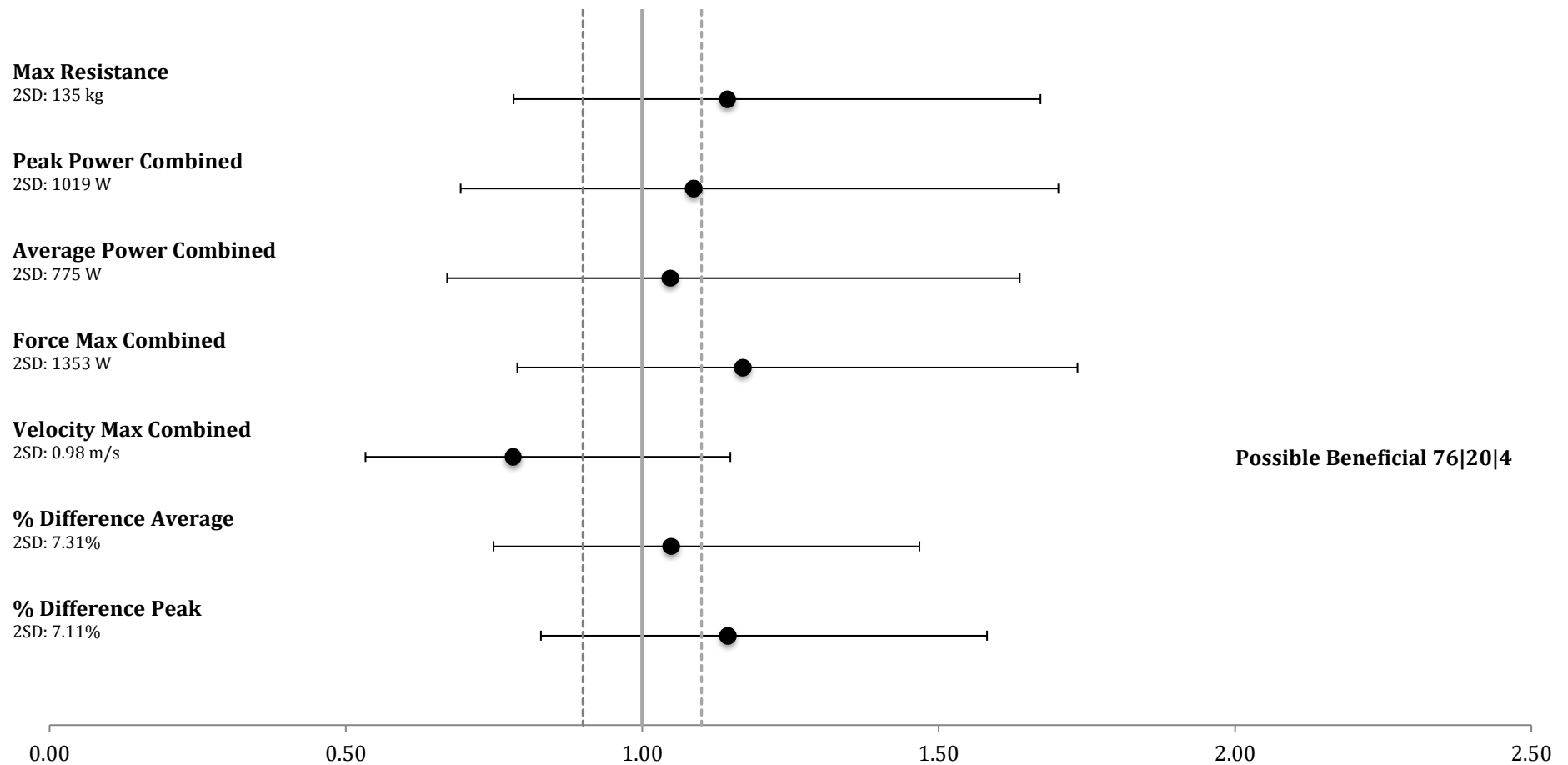


Figure 7.2: Risk ratio of variables for various lower limb strength, power and asymmetry variables and lower limb injury risk for relevant injuries.

Dashed lines represent the boundaries of smallest worthwhile decrease/increase in risk of injury

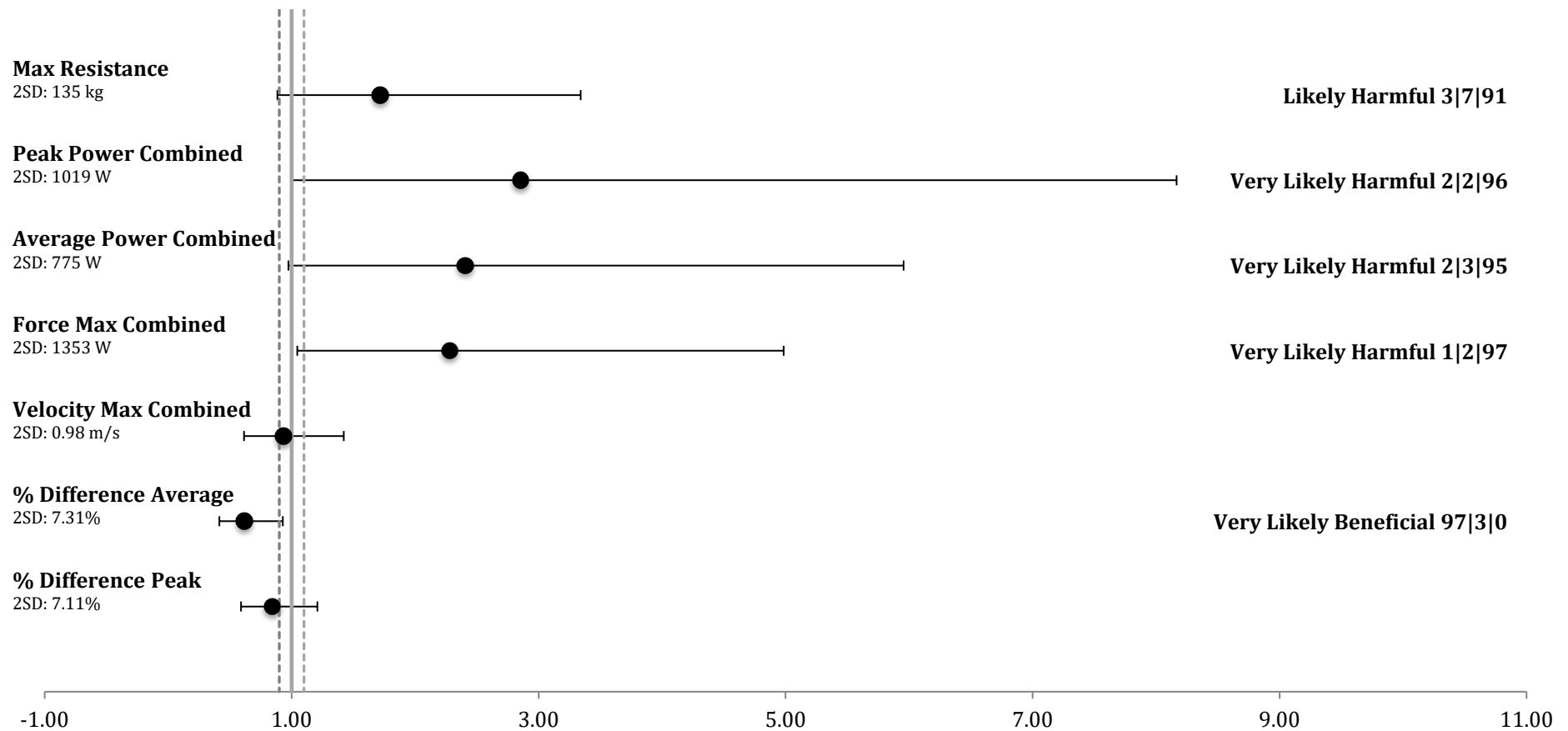


Figure 7.3: Risk ratio of variables for various lower limb strength, power and asymmetry variables and lower limb injury burden for all injuries.

Dashed lines represent the boundaries of smallest worthwhile decrease/increase in risk of injury

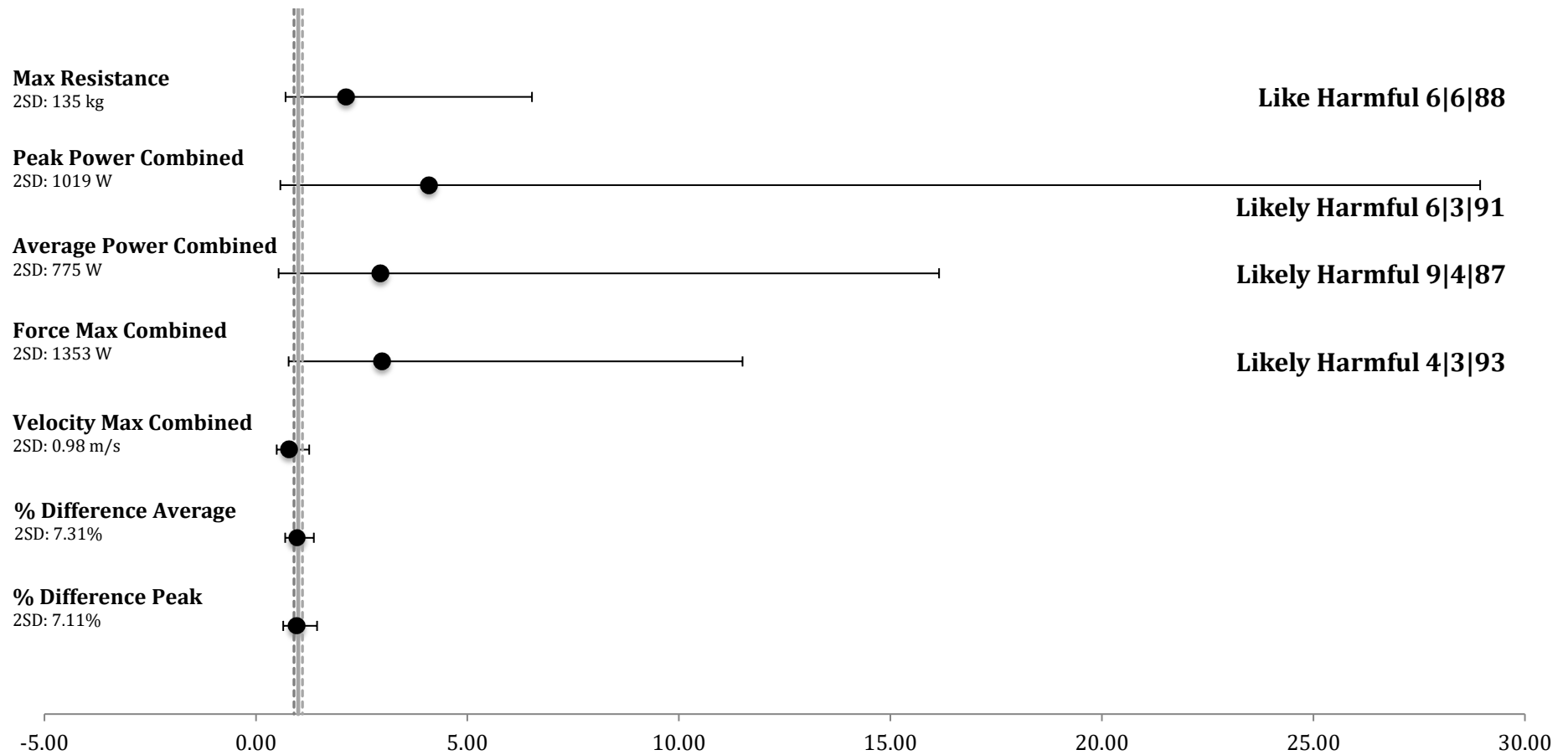


Figure 7.4: Risk ratio of variables for various lower limb strength, power and asymmetry variables and lower limb injury burden for relevant injuries.

Dashed lines represent the boundaries of smallest worthwhile decrease/increase in risk of injury

7.4 Discussion

The aim of the current study was to investigate associations between lower limb strength, power and bilateral asymmetry of elite soccer players and training/match lower limb injury incidence and burden over a competitive season. When investigating injury incidence, ‘likely’ harmful effects were seen for increased Force Max Combined in relation to all injuries, whilst ‘possibly’ beneficial effects of increased Velocity Max Combined were seen in relation to relevant injuries. When looking at injury burden, ‘very likely’ and ‘likely’ harmful effects were seen for increased Maximal Resistance, Peak Power Combined, Average Power Combined and Force Max combined for all and relevant injuries. A ‘possible’ beneficial and ‘very likely’ beneficial effect was seen for % Difference Average asymmetry for all injury incidence and all injury burden respectively but no effects were seen for % Difference Average asymmetry and % Difference Peak asymmetry for relevant injury incidence or burden.

The current study established an injury incidence rate of 8.1 per 1000 h overall and 5.6 and 20.2 per 1000 h for training and matches, respectively. This compares well with the range for overall injury incidence (7.4-7.7 per 1000 h exposure) and for training injury incidence (3.4-5.9 injuries per 1000 training hours) established previously in the literature (Hawkins and Fuller, 1999; Ekstrand et al., 2004a; Ekstrand et al., 2011a; Arnason et al., 2004; Häggglund et al., 2013; Carling et al., 2018). The current values are however moderately lower than 25.9-40.5 injuries per 1000 h in match play previously found (Häggglund et al., 2013; Ekstrand et al., 2011a; Carling et al., 2010). The injury count per player of 1.9 injuries per season in the current study is also very comparable 2.0 per player per season previously reported (Ekstrand et al., 2011a). Injury burden in the current study was 145 days per 1000 h exposure, with a mean of 34 days lost and median of 17 days lost per injury. These results correlate well with the previous literature looking into injury burden in soccer which found an injury burden value of 130 days per 1000 h exposure (Häggglund et al., 2013), a mean of 37 days lost per injury (Ekstrand et al., 2011b) and a median of 18 days lost per injury (Leventer et al., 2016). Clearly, due to the restriction on injury definition for ‘relevant’ injuries, injury incidence rates of 3.0 and 8.9 per 1000 h of training and match exposure, respectively, and overall injury burden of 68 days per 1000 h exposure is noticeably lower. However, the notably greater rate and burden of

injury in match play in comparison to training remained similar to overall injury values.

Whilst looking at incidence of injury, the current study found ‘likely’ harmful effects of increased Force Max Combined for all injuries and ‘possible’ beneficial effects of increased Velocity Max Combined for relevant injuries. As Force Max Combined is calculated by extrapolating a line of best fit through peak force values from each repetition down to 0 m/s (Figure 3.3), results in the current study suggest that individuals with the ability to generate power through moving heavier mass have a ‘likely’ greater risk of injury. This conflicts with previous research that suggests lower limb strength weakness increased risk of injury (Fousekis et al., 2011; Timmins et al., 2016) and that increasing lower limb strength decreases injury incidence (Askling et al., 2003; Heidt et al., 2000). Although contradictory to the previous body of research, findings in the current study may suggest that individuals who rely on superior force values rather than a balanced combination of force and velocity for power production are at an increased risk of injury supporting the concept of power production resulting from the balanced combination of both elements. Indeed, Mendiguchia et al. (2016) found disturbances in sprint force-velocity profiles through an increase in maximal force and decrease in maximal velocity immediately prior to hamstring injury in rugby players suggesting that an unbalanced ratio between strength and velocity may affect injury incidence risk. Interestingly, the Maximal Resistance variable (highest force successfully pushed with both legs) in the current study showed no association with training-related injuries, suggesting that, although the parameters are similar, the extrapolated maximal force capability may be a more sensitive marker for injury risk than highest produced strength output from each test. ‘Possible’ beneficial effects for Velocity Max Combined for relevant injury incidence suggest that individuals with the ability to generate high power output through moving mass quickly have a ‘possible’ reduced risk of injury. Although pure velocity of movement in the absence of the influence of muscular strength has not been extensively researched, a proposed mechanism for this may be that the average intensity of a match or training session is not excessively stressful to increase injury risk in individuals that are able to produce the superior high velocity capabilities.

The conflicting effects of Force Max Combined and Velocity Max Combined on injury incidence risk in the current study, with no effect seen for either power

variables, suggest that assessment of overall power output (a combination of force and velocity) as a marker of injury risk potential in soccer players may not be sufficient. Furthermore, the current findings show the need to assess the velocity and force components of power output to better understand injury risk from lower limb strength and power testing. Without this, it could be assumed that individuals with similar power output may have similar injury risk potential, however, with very different force and velocity components, this may not be the case. This is supported by Mendiguchia et al. (2016) who, following their research mentioned above suggested regular monitoring of force production for injury prevention. Further research should be aimed at establishing the association between maximal force and maximal velocity of movement with injury risk in soccer players.

In contrast to injury incidence, the effects of strength and power output on injury burden in soccer players in the current study consistently found ‘likely’ and ‘very likely’ harmful effects of increases in Maximal Resistance, Peak Power Combined, Average Power Combined and Force Max Combined on days lost through all injuries and through relevant injuries. Although there is limited research considering the injury burden from different strength and power profiles, these findings correlate well with previous research in soccer looking at injury incidence and power output (Henderson et al., 2010; Engebretsen et al., 2010), which both established superior power outputs as a risk factor for injury. Specifically, these findings are similar to Engebretsen et al. (2010), who established 40 m sprint time as a risk factor for groin injury in soccer.

Combining the effects from injury incidence and injury burden in association with lower limb strength and power, results from the current study suggest that although high Force Max Combined values may have an increased effect on injury incidence, only small effects are seen for differing strength and power profiles in relation to the number of injuries sustained. However, if injury does occur, the time lost/burden of injury is markedly greater in soccer players with higher strength and power outputs. Whilst there is limited research to compare against, the present results suggest that soccer players with an ability to produce high power outputs are more likely to sustain more severe injuries and practically, these results suggest that special consideration needs to be given to individuals with superior strength and power profiles at times in a soccer season when injury risk potential is higher than normal, for example, during a

period fixture congestion (Bengtsson et al., 2013). The large confidence intervals (Figure 7.2 and Figure 7.3) and percentage increases for clear effects (72-309% increase in injury burden) seen in the current study for injury burden were due to the large range of days lost through injury (range: 1-291 days). This range highlights the importance of assessing injury burden as well as injury incidence as it shows the varying impact any single injury can have.

In the current study, ‘possibly’ and ‘very likely’ beneficial effects were seen for increasing % Difference Average asymmetry in relation to injury incidence and injury burden for all injuries, respectively. Although beneficial effects of large bilateral power asymmetries for all injuries in the current study conflict with previous research that found large bilateral asymmetries increasing the risk of injury in soccer players (Croisier et al., 2008; Fousekis et al., 2010; Knapik et al., 1991), the current study suggests that asymmetry of moderate magnitude, similar to that seen in the current study, may be learned as an adaptation of training and as a result protect individuals during soccer specific actions. For example, a strength and power asymmetry in favour of an individual’s preferred striking leg may protect them from injury when striking at higher velocities than would be completed with the non-preferred striking leg. Interestingly however, when injury definition was narrowed to ‘relevant’ injuries only, no clear effects with asymmetry were seen. As these effects did not hold when injury definition was restricted to ‘relevant’ injuries only whilst the effects for other strength and power variables remained across both injury definitions, it could be suggested that beneficial effects found for increasing % Difference Average asymmetry in relation to all injuries may be a result of a type I error due to the inclusion of injuries not relevant to lower limb strength and power. If true, these findings justify the selection of a subset of ‘relevant’ injuries in the current study and interpretation of effects of lower strength and power with ‘all’ injuries should be interpreted with appropriate caution. Regardless, no negative effects were seen for large asymmetries for all or ‘relevant’ injuries in the current study suggesting that asymmetry may not be a risk factor for injury, in contrast to the current research area. The differences in finding in the current study could be attributed to previous research being completed using only isokinetic dynamometry, or looking solely at eccentric hamstring and quadriceps bilateral strength asymmetries in comparison to the more dynamic movement of the seated leg press. Additionally, the current study may not

have had enough participants with large bilateral power asymmetries to accurately establish a correlation with injury risk. Indeed, only 12% of participants (12 out of 104) had an average asymmetry larger than the most conservative asymmetry threshold of 8% that has been found associated with an increased injury risk (Orchard et al., 1997). If this is increased to the more widely accepted 10% and 15% (Croisier et al., 2008) thresholds, participants in the current study with asymmetry values over these thresholds decreases to 6 % and 3%, respectively. In support of this, normative average power bilateral asymmetry values found in Chapter 5 were a modest $4.3 \pm 4.1\%$. Therefore, it may be the case that individuals with very high asymmetry are unable to remain/thrive within soccer at an elite level and/or, as bilateral asymmetry is a recognised risk factor for injury (McCall et al., 2014), this modifiable factor has already been addressed in the current elite athlete population, limiting its association with injury incidence. Regardless, as the current study did not establish any association between bilateral asymmetry and injury risk or burden, yet it has been recognised that bilateral asymmetry is associated with increased injury risk in soccer, results from the current study suggest that seated leg press testing should be used alongside other lower limb strength and power testing modalities to evaluate bilateral asymmetry in greater detail. Indeed, considering the complex nature of injuries, a battery of tests including isolated hamstring testing would be appropriate to obtain a complete lower limb strength, power and asymmetry profile of an elite soccer player.

Although the current study was exploratory in nature and therefore a univariate analysis approach was considered most appropriate, the lack of multivariate analysis of lower limb strength and power in relation to injury should be considered a limitation. Given the multi-factorial nature of injury incidence, investigating the effect of lower limb strength, power and asymmetry on injury in isolation may give simplified results and the interaction between, and combined effects of, lower limb strength, power and asymmetry variables on injury should be considered. Similarly, the effects of additional confounding variables such as age or injury history were not accounted for in the current study and could have an impact on findings. As such, to follow on from initial findings in the current study, future research should aimed at investigating the impact of interactions between lower limb strength, power and asymmetry on injury using through comprehensive multivariate analysis.

Another potential limitation of the current study is that strength, power and asymmetry measurements were taken in pre-season only and subsequently used to associate with injury incidence and burden over the subsequent 11-month season without accounting for individual's potential strength and power changes over this time period. Although Chapter 5 established that strength, power and asymmetry values remained stable throughout the season for some individuals, significant improvements in strength and power were seen across a season with the U17 playing squad. Therefore associating pre-season testing results with injuries that occurred later in the season may not have been reflective of the individual's strength and power profile at the time of injury. Indeed, alongside absolute values, it may be that large positive or negative changes in an individual's strength and power profile are associated with increased injury risk also. Future research should aim to investigate the longitudinal effect of changes in soccer players' strength and power profiles on injury risk.

7.4.1 Conclusion

In conclusion, the current study established 'likely' harmful effects of increased Force Max Combined for all injury incidence and 'possible' beneficial effects of increased Velocity Max Combined for relevant injury incidence. 'Likely' and 'very likely' harmful effects of increased Maximal Resistance, Peak Power Combined, Average Power Combined and Force Max Combined were seen for all and relevant injury burden. Although 'possibly' and 'very likely' beneficial effects were seen for % Difference Average asymmetry for all injury incidence and burden, no effects were seen for % Difference Average or Peak asymmetry for relevant injury incidence or burden. Results suggest that an individual soccer players' strength and power profiles does not influence incidence of injury, however those with high strength and power output are more likely to have a larger injury burden if injury does occur. Additionally, lower limb left-right power asymmetry assessed through seated leg press testing does not seem to influence the incidence or burden of relevant lower limb injuries in soccer players.

CHAPTER 8- GENERAL DISCUSSION

8.1 Introduction

Within elite soccer, individuals and teams are continually looking for technical, tactical and physical advances in an attempt to improve team performance and ultimately team success. Within a sports science and medical department of a soccer club, these advances are aimed to improve physical performance and reduce injury incidence and burden. Amongst many other elements, lower limb strength, power and asymmetry are considered important for physical performance and reduction of injury incidence in soccer. Therefore, it is prudent to ensure that appropriate testing of lower limb strength, power and asymmetry and subsequent accurate analysis of testing results is included in physical testing and monitoring within a soccer team.

When evaluating the literature around lower limb strength, power and asymmetry testing in soccer, the vast majority of the research has been completed using isokinetic dynamometry or various jump testing protocols. Whilst both methods provide feedback on strength, power and asymmetry, criticisms have suggested that isokinetic dynamometry lacks applicability to sporting movement to be relevant whilst jump-testing protocols may lack the detail of data to identify performance issues. Therefore, it could be suggested that neither protocol is appropriate for testing in soccer.

Additionally, little research has been published identifying thresholds of strength, power and bilateral asymmetry associated with injury risk meaning that evaluation of testing results is limited. The Keiser Air420 pneumatic resistance based seated leg press is a tool which is commonly used within Premier League soccer teams for both lower limb strength and power training and assessment. Whilst it involves offloaded, applicable movements and provides detailed physiological feedback, within the elite sport setting there has been no research published investigating its use as a testing tool in soccer.

Therefore, the aim of this thesis was to investigate the use of the pneumatic resistance seated leg press in soccer players to gain a greater depth of knowledge on its applicability as a testing tool and the results it provides for lower limb strength, power and bilateral asymmetry in soccer players.

In order to address this, a series of five questions were introduced in the general introduction. This discussion will begin by addressing and summarising the main findings from investigations into these questions separately. Then these findings will be discussed as a whole to answer the overall aim of the thesis and practical implications for the applied environment will be suggested. This chapter will then consider some of the methodological issues that were apparent throughout the research process and finally propose some potential areas of further research that could be completed.

8.2 Addressing the research questions

- i. Assessment of the reliability of elite soccer player performance on the Keiser Air420 through a repeated test-retest protocol.

Reliability testing did not establish any significant differences between tests with typical percentage error values $< 6.9\%$ and ‘good’ reliability ($ICC > 0.76$) for all strength and power variables following completion of a standardised leg press test on three separate occasions. Bilateral asymmetry variables calculated around the average power values were found to be the most reliable measures, whilst asymmetry values calculated around the average of the last 4 repetitions showed significant differences between trials, limiting their reliability.

- ii. Establish the age group and playing position dependent typical characteristic lower limb strength, power and asymmetry markers for elite soccer players using the Keiser Air420.

Typical characteristic lower limb values for an elite soccer player completing the standardised seated leg press protocol were established with, most notably, an average bilateral power asymmetry of $4.3 \pm 4.1\%$ found. U21 playing squad showed higher Average Power Combined and Velocity Max Combined than the average of all players but no other differences were seen across the squads. When looking at playing position variations, Centre Back and Strikers were found to have ‘likely’ higher strength, power and asymmetry values than all other positions.

- iii. Establish age group dependent variation in strength, power and asymmetry over a season in elite soccer players using the Keiser Air420.

Across a soccer season, the youngest professional squad (U17) showed ‘likely’ small increases in lower limb strength and power whilst U18 and U21 squads remained largely unchanged. There were no significant variations in any bilateral asymmetry values across the soccer season either.

- iv. Investigate the sensitivity to change of lower limb strength, power and asymmetry of elite soccer players assessed using the Keiser Air420 through testing around a competitive soccer match.

No differences in lower limb strength, power or asymmetry were found immediate post-match with ‘possible’ decreases seen in Peak Power Combined at 24 h post-match when an obvious outlier was excluded. When assessing individual lower limb strength and power responses to match participation, large variation within the group was clear suggesting individual differences in physiological impact of match participation 24 h post-match. Although no differences were seen in % Difference Average, 5 of 19 participants notably increased their asymmetry values immediately post-match and at 24 h post-match reinforcing individual variation in response of lower limb strength, power and asymmetry following match participation.

- v. Assess the capability of the Keiser Air420 as a screening tool for injury risk through investigation into the association between pre-season lower limb strength, power and asymmetry and subsequent season-long injury incidence and injury burden of elite soccer players.

Although there were ‘possible’ beneficial effects of increased Velocity Max Combined and ‘likely’ harmful effects of increased Force Max Combined in relation to injury incidence, limited effects were seen for pre-season strength, power and bilateral asymmetry values and overall injury incidence. However, clear ‘likely’ and ‘very likely’ harmful effects were seen for increased strength (Maximal Resistance and Force Max Combined) and power (Peak Power Combined and Average Power Combined) variables in relation to number of days injured per season. Beneficial effects of increasing asymmetry were found in relation to all injuries whilst no effect

was found in relation to ‘relevant’ injuries. Findings suggest that stronger, more powerful individuals are at no greater risk of injury incidence but are likely to suffer a greater injury burden if injury occurs. Additionally bilateral asymmetry was found to have no effect on ‘relevant’ injury incidence or burden.

8.3 Overall discussion and practical implications

Despite its use in the applied environment, there is very limited research relating to the use of the Keiser Air420 seated leg press in elite soccer players. This thesis aimed to investigate the applicability of the Keiser Air420 as a valid lower limb strength and power testing device in elite soccer, to give practitioners assurance around its use, whilst also providing context around the evaluation of elite soccer player lower limb strength and power.

As mentioned previously, when initially evaluating the literature in the area, there was no published research relating to elite soccer players using the pneumatic seated leg press. Therefore, as a starting point and to give any further research reliable grounding, Chapter 4 aimed to evaluate the reliability of elite soccer players using the seated leg press as well as assessing the reliability of multiple lower limb asymmetry calculations.

The results from Chapter 4 established that all lower limb strength and power output from the participants on the seated leg press could be considered reliable with an excellent degree of certainty. In comparison, the limb asymmetry calculations produced conflicting results. As the number of parameters investigated was already large, differentiation between the reliability of these calculations allowed for some to be removed from further analysis as it was deemed that they would not add any more value. For example, as significant differences were found between the first and second trials for the Last 4 repetitions bilateral asymmetry variables (comparison between left and right limb average power output over the last 4 repetitions only), these parameters were not considered reliable enough for use in the subsequent research. Interestingly, these variables were selected for reliability research on practitioner experience, as it was seen that differentiation between left and right leg power output was much more evident at heavier loads, however the reliability of this variable had not been investigated. This provides a good example to the applied sporting environment of the importance of completing controlled research to

investigate any experience-based assumptions in order to validate them.

Subsequently, it has been suggested by one of the designers of the testing device that any leg preference at very high load may be due to an individual self-selecting to concentrate their effort through one leg followed by the other without any physiological difference in the legs, which would support the lack of consistency between consecutive trials. No differences were seen between trials two and three for last 4 repetition asymmetry variables suggesting that there may be a learning effect of pushing the heavier loads. However, as all participants were well accustomed to the testing protocol, it appears that leg press at higher resistance results in larger variability in bilateral power asymmetry limiting the last 4 repetition asymmetry variables as a reliable measure. Although Peak Power asymmetry variables showed the highest typical error values across all three tests, as this asymmetry parameter provides a snapshot of the individual's highest power output on each leg, an element of performance that is highly likely in a sporting context, this variable was retained. Within Chapter 4, Average, Peak and Last 4 Repetition variables were calculated in three separate ways to see whether the calculation method had a differential impact on the bilateral asymmetry value attained. Whilst Symmetry Angle calculations resulted in depressed asymmetry values in comparison to % difference across all participants, no differences in change between trials were found for either measure. As Absolute Difference variables showed the difference, in watts, between left and right legs, larger values were found in comparison to the other two calculation methods but again, no differences were found between trials for the different calculation methods. As no differences were found between calculation methods, it was decided that it was most appropriate to continue with the methods used most commonly in the applied environment, which were Absolute Differences and % Difference Asymmetry. Symmetry Angle calculation was removed from further analysis as it involved complex calculation that may not be relatable to both coaches and playing staff as well as producing depressed values which were not comparable to the current literature. Subsequently, for Chapters 6 and 7, Absolute Difference asymmetry variable was also excluded from analysis, as it was found to not be adding any unique research findings beyond % Difference Asymmetry and therefore deemed an unnecessary additional variable.

To accurately establish any changes between consecutive tests, reliability testing classified a positive number as a right leg dominance and a negative number as a left leg dominance. Through the rest of the research in the thesis, bilateral asymmetry values were stated as positive regardless of their left or right dominance. As previously stated this was done to give a 'true' reflection of the average magnitude of asymmetry across the group and so that 'positive' asymmetries did not cancel out 'negative' asymmetries. Additionally, the current thesis was not concerned by the direction of limb dominance on performance but more significantly the magnitude of that dominance. A potential negative result of doing this was that individuals with large fluctuations between tests, for example from 10% left dominance to 10% right dominance, would be missed in the response to match play research in chapter 6. However, on analysis of the data for this chapter, large fluctuations such as this were not apparent and it was deemed smaller fluctuations of asymmetry either side of 0% (e.g. $\pm 5\%$) were not large enough to affect injury risk. Therefore, the inclusion of the values regardless of direction were considered more appropriate for analysis of the average of the group and for completeness, the count of individuals that moved between asymmetry risk bandings was also stated in Chapter 6.

Once reliability of the seated leg press was established, Chapter 5 established typical in-season characteristic values for an elite soccer player using the seated leg press dependent on playing position and playing squad. This research was completed to assist the applied practitioner in evaluation of testing results if normative data was not already established within their environment. Additionally, establishing these values relative to playing position enables greater specificity in feedback of testing results and potential training methodology. Across playing positions, results showed that Centre Backs and Strikers have superior strength and power values than all other positions. These results suggest that these playing positions should only be compared against the average of their respective positions whilst all other playing positions can be compared against the average of the group. Additionally, it suggests that both Centre Backs and Strikers should be producing superior strength and power output to the rest of the squad; and could be suggested that higher loading training should reflect this. Practically, these findings are of great use in the applied environment because they enable the practitioner to have greater confidence that interpretation of test results are accurate for each playing position and led a practitioner towards a

more individualised strength and power training programme dependent on playing position.

When looking at the differences between playing squads at a single time point in October, only 'likely small' superior strength and power values were seen for U21 playing squad in comparison to U17 and U18 squads. However, when looking at seasonal variation, across a whole season, U17 playing squads showed significant increases in comparison to their pre-season values whilst U21 squad only maintained strength and power values across the season. Taking these two findings together, it could be suggested that if squad comparisons were completed at April Testing, due to improvements made by U17 playing squad over the season, strength and power differences between the playing squads would be smaller. Indeed, the significant improvements seen by U17 playing squad across the season support the use of the October testing for between squad comparisons as it provides an overview of strength and power capabilities of each playing squad prior to physical adaptations and improvements that were seen to occur from consistent overloaded physical training over a season. Significant improvements over a season that were seen with U17 playing squad but not seen across the other two squads could be attributed to the larger increase in physical stimulus experienced by the U17 squad as they transition from part time to full time training with a heavy physical development emphasis through-out. It should be noted that, although this research gives an indication of playing position and playing squad dependent elite soccer players performance on a seated leg press, it is only reflective of one team and, due to large differences in training programmes across clubs, potentially cannot be generalised across all professional soccer teams.

The lack of improvement in the U18 and U21 squads was likely due to these groups moving away from isolated physical development and intensive training and towards competition and match play. This research supports previous studies that have found no increases in strength and power over a season despite a consistent training stimulus (Thomas and Reilly, 1979; Casajús, 2001; Silvestre et al., 2006). Therefore, the challenge for the applied practitioner working with older playing squads focused on competition is to try to improve strength and power across a season without negatively impacting on match play performance through excessive fatigue. As Chapter 6 demonstrated that for some individuals there was no decrease of physical

output following match play, there may be opportunity to introduce lower limb strength and power training in the days following a match that were not previously considered in an attempt to counteract this issue.

Chapter 5 also utilised the smallest worthwhile change created from typical error values established in Chapter 4 when assessing the significance of the magnitude in variation in strength and power across a season. This was also subsequently used to evaluate the significance of variation in strength and power following match play in Chapter 6. The use of smallest worthwhile change as a marker for significance provided population specific thresholds to evaluate the results of the longitudinal research and meant that any variation between tests was considered relative to the natural variation between tests. This was considered as the most appropriate threshold to set for our research into elite soccer players as the margins between success and failure in elite sport are fine and therefore any variation in performance in elite sport outside of the natural variation can be considered relevant. In the applied context, establishing a range of meaningful change around all lower limb strength and power variables means that accurate assessment of differences between tests is possible where previously it had been much more subjective.

As mentioned, Chapter 6 found no clear decreases in lower limb strength and power performance immediately post-match in comparison to baseline testing and only 'possible' decrements in Peak Power Combined when an obvious outlier was excluded 24 h post-match. When looking at the individual response to match play across all variables, it is clear to see that there is large variation in change in lower limb strength and power to match play. This was reflected in the notably higher standard deviation in the change between testing points in Chapter 6 in comparison to reliability testing in Chapter 4 (260 W SD vs. 161 W SD for Peak Power Combined). Interestingly, these results confirm what applied practitioners in elite team sport have often considered, that is that group results will show a rough overview/trend of physiological response but for optimal results, individual assessment is necessary. If true, this provides an issue for applied research in small elite populations, in that the averaged results of any testing group are only going to accurately reflect the true response of a few individuals. It also provides an issue for the applied practitioner who may need to train/manage a group of 25+ players but knows that an individualised training is optimal. Within the applied environment, these results

suggest that to provide optimal, individualised service to elite soccer players, large support staffing is needed.

As only small differences were seen around match play, Chapter 6 also highlighted that the Keiser Air420 may not be sensitive enough to monitor for fatigue-induced changes in elite soccer players following match participation. Similarly, as no consistent correlations were found between seated leg press performance and injury incidence in Chapter 7, seated leg press with elite soccer players may not be considered an effective screening test to establish associations with injury incidence. However, it may be an effective tool for identification of individuals at higher risk of injury burden as Chapter 7 clearly established that individuals with higher strength and power capacity had a higher risk of injury burden. These results may be due to the fact that individuals with a capability for high power output contract their muscles at greater velocity and with a greater rate of force development meaning that if any tear or lesion occurs, damage will be significant. Therefore, through this research, practitioners should be able to isolate when it is appropriate to test soccer players using the seated leg press and how to interpret the results. It may be suggested that pre-season screening is appropriate as individuals can be evaluated in comparison to typical values found in Chapter 5 and those with notably high strength and power can be tagged as potential injury burden risks that require closer monitoring through-out the season. Once flagged, adjustment of training and match load may be recommended for these individuals during periods of high training load (e.g. pre-season), fixture congestion or when disturbances in daily objective and subjective wellness markers such as subjective muscle soreness or fluctuations in hormonal results are reported. In line with the findings in Chapter 7, it appears that testing for bilateral asymmetry as an injury risk factor through seated leg press is not appropriate as no association was found with Average or Peak % Difference asymmetry and relevant injury risk or burden. That being said, the seated leg press does offer off loaded high resistance or velocity training and assessment that could be of use for identification on asymmetry in load compromised individuals returning from injury.

Through the results attained, the current thesis highlights a more general issue within elite sport of the need to evaluate and assess the purpose of the tools used in order to utilise them in the most efficient and effective manner. As mentioned previously, the Keiser Air420 seated leg press is used extensively in elite soccer, however this is the

first published research evaluating it in the current population. Whilst the research completed has confirmed the reliability of it as a tool, it has also refuted its ability to monitor for fatigue and likelihood of injury incidence, therefore adding knowledge to the use of the tool in the industry and hopefully improving practice. As a large volume of data points are needed before analysis can be completed into the use of any tool and as time-consuming statistical analysis may not be a priority in an industry concerned with results, it appears that analysis of the effectiveness of testing and monitoring tools is sparse in elite soccer. However, if completed, it can streamline and optimise support services and training methods and therefore, time and effort should be delegated towards it for all testing and monitoring protocols used.

Prior to completing the current thesis, the Keiser Air420 seated leg press was used within soccer to assess for, amongst other things, left-right leg asymmetry as previous research had established its role as a risk factor for injury. The current thesis has established that:

- Typical magnitude of asymmetry within soccer players is relatively low: $4.3 \pm 4.1\%$.
- Match play participation has minimal effect on the magnitude of asymmetry.
- Asymmetry has no meaningful association with incidence or burden of 'relevant' injuries.

Therefore, it could be suggested that it may not be appropriate to use the seated leg press in fit soccer players for assessment of lower limb asymmetry. Indeed, as mentioned in Chapter 7, low association between asymmetry and injury incidence found in the current thesis may not exist merely because average asymmetry in elite soccer players in the current research is low. Although the reason behind this unknown, it could be speculated that it may be because individuals with consistently high asymmetry values do not survive in elite soccer up to professional standard age (>16 years). Similarly, it could be said that those individuals with tendency for asymmetry values to grow significantly following intense repeated actions such as match play also may not survive in elite soccer. Contrastingly, as left-right lower limb asymmetry has previously been identified as a risk factor for injury, it could be that by the time elite players reach professional standard age, any asymmetry issues have been addressed and rectified. Or finally, it may be that the seated leg press is not an

appropriate tool to identify asymmetries in soccer players. Although the reason behind low average asymmetry in the group is unknown, as has been seen in the current thesis, without asymmetries of large magnitude, establishing association with injury incidence and burden is difficult.

8.4 Evaluation of results in the applied environment

As noted above, the aim of the current research was to inform on and assist with the use of the Keiser Air420 seated leg press in the applied environment.

Most obviously, Chapter 4 illustrates that practitioners can have confidence in testing results through good reliability of test-retest results and provides example ranges of meaningful change to set around longitudinal data for greater interpretation of results. Chapter 5 provides practitioners with playing position and playing squad dependent typical characteristic values to act as a comparison to current testing results. As Chapter 5 established that asymmetry magnitudes, on average, were low in elite soccer players assessed through the Keiser Air420, practitioners should seek to validate these findings through completion of a battery of lower limb strength and power tests to ensure potential significant asymmetries are not being missed by the current test. Within the current club in which the testing occurred, establishing these typical characteristic values has enabled more accurate evaluation of playing position dependent results and the ability to set physical targets for individuals as they progress through age dependent playing squads. Similarly the evaluation of strength, power and asymmetry over the season has enabled practitioners at the current club to evaluate their training programmes over a season with ranges of meaningful change set for all individuals as a marker of progression and effectiveness of a training programme.

Findings from Chapter 6 stress the importance to the applied practitioner of the need for individual monitoring with regard to the impact of match performance on lower limb strength and power immediately post or 24 h post-match. The lack of physical decrement seen immediately post-match in some individuals should give practitioners the confidence to schedule lower limb strength and power training sessions across this time period if necessary. This is something that may be of particular importance to teams with high competition schedule such as the U18 and U21 squads who were found to show no improvements across a season in Chapter 5. Findings from Chapter

6 have also established that the Keiser Air420 may not be an appropriate tool to assess for lower limb strength and power decrements post match due to it's lack of sensitivity.

Finally, Chapter 7 established the need to assess individuals through seated leg press testing as soccer players with high strength and power capabilities were found to be at a considerably increased risk of high injury burden. Following on from this, results suggest that players that can produce high strength and power values through seated leg press should be monitored closely at periods such as a concentrated match schedule or intense training period such as pre-season when fatigue and injury risk increases, as these individuals are at a greater risk of injury. Conversely, Chapter 7 also demonstrated that asymmetry assessed through seated leg press in elite soccer players is not associated with injury incidence or burden. Whilst this does not suggest that bilateral asymmetry is not associated with injury incidence, it does suggest that another testing modality and/or a battery of tests may be needed to evaluate bilateral asymmetry in a greater detail.

8.5 Discussion of Methodological Principles

8.5.1 Difficulty collecting accurate data in an elite practical environment.

As is common in applied research, data collection in the current thesis was difficult due to continual conflict between the 'noise' of the applied environment and need for a controlled environment for optimal testing. Whilst the need to control all external variables such as diet/recovery modalities/psychological stresses was dampened by the fact that the research completed was to aiming to be a reflection of an applied environment, consistency in the quality of testing data was of the upmost importance through-out. Although distractions from team-mates, coaching staff or upcoming training/match play were inevitable during the majority of testing due to the placing of the testing equipment in a functional gym during a soccer season, measures were taken to ensure consistency.

Players were repeatedly exposed to the warm up and testing protocol prior to completing any research testing to limit any potential distractions from the test. Likewise, the research questions surrounding each testing were clearly explained to

the participant and any player or coaching staff close to the test to reinforce the importance of maximal effort and minimal distraction through-out.

One of the challenges in data collection for Chapter 6 was the maintenance of consistent maximal effort when testing over 3 consecutive days. This was, in part, due to tedium of completing the same maximal task repeatedly, but also due to the fact that variability in effort may have increased as tests were completed around participation in a competitive match. Participants may have been inclined to work sub-maximally on the day before the match in an attempt to not overly exert themselves ahead of match play and effort immediately post-match could have been largely influenced by individual or team performance. Explanation of the reasons behind testing and potential benefits from completing accurate maximal testing such as reduction in injury risk were continually reinforced in an attempt to alleviate this.

Although some of these problems are outside of the control of the researchers, the use of findings from reliability testing in Chapter 4 in Chapters 5 and 6 was also completed to minimise this. As smallest worthwhile change parameters were calculated from data collected in the same environment as subsequent studies, ideally any variation from the environmental noise in the longitudinal studies should be contained within this range.

8.5.2 *Small sample sizes*

Another limitation of working in the elite applied environment is the inevitably small sample sizes. In the current thesis, the lack of total potential participants ($n \approx 75$) available further reduced by injury, availability and ability to fit the methodology criteria meant that participant numbers in all chapters were small.

However, by definition, elite soccer players are a small number of individuals, particularly relative to the total people that play soccer worldwide as discussed in the introduction and therefore in order to accurately address the questions on an elite population, the research had to be completed on a small number of soccer players. Due to this, researchers should be cautious of the implications of low powered studies when interpreting results found. It is also worth noting that all data collected was from players within only one Premier League football club and therefore due to different player recruitment and training methodologies at different clubs, researchers

and practitioners should be cautious when interpreting this data outside of this unique environment.

A number of methodological adjustments were made throughout the research, in an attempt to maximise sample size. For example, in Chapter 5, mid-season testing data was taken for 62 participants to calculate playing squad and playing position specific typical normative data. In order to do this, data collection had to take place over 3 consecutive seasons to ensure an adequate number of participants in each playing position and playing squad. To progress the research further, the authors would have liked to study the interactions between playing position and playing squad, however as some playing positions only had 1 or 2 entries per age group, it was not feasible to study these interactions accurately. Additionally, in the same chapter, longitudinal season-long data was taken for a sub-group of 45 participants. Although seasonal fluctuations were broken down across 3 playing squads, it was considered unfeasible to do the same for each playing position with low and variable participant numbers for different playing positions ($n=4$ for goalkeepers vs. $n=20$ for midfielders).

In Chapter 7, 104 player seasons were collated over a 3-season period to investigate the correlation between seated leg press strength, power and asymmetry and injury incidence and burden. Across the 3 seasons, 61 players were used to obtain 104 player seasons, with 25 participants occurring in two seasons and 9 participants occurring in all three seasons. Whilst this was deemed necessary to increase the number of player seasons and therefore strengthen the analysis of association, it was essential to use Generalised Estimating Equations in the analysis of data to account for it.

8.5.3 *Use of Magnitude Based Inferences*

At points within the current thesis, interactions and effects were evaluated using magnitude based inferences as a preference over the more traditionally used null hypothesis significance testing. Where appropriate this decision was taken, with an aim to counteract some of the limitations of null hypothesis significance testing and to obtain more meaningful interpretations, and therefore practical implications, from the dataset.

Null hypothesis significance testing has been traditionally used within research to evaluate relationships and is based around investigating whether the null hypothesis

(A has no influence on B) is untenable. Once this is proven, then the opposite (A has an influence on B) can be accepted. To establish whether a null hypothesis is proven true or not, a p-value is calculated from the data set, and typically established as true if $p > 0.05$ and false if $p < 0.05$ (There is $< 5\%$ chance of obtaining that A has no influence on B).

However over the past 10 years, this method has come under criticism for some of its considered limitations (Batterham and Hopkins, 2006; Hopkins, 2010; Winter et al., 2014; Cumming, 2012). One major limitation identified with the null hypothesis significance testing method is that it can only give the author and reader a binary response without informing on the magnitude of the effect- something either has a significant effect or it does not (Batterham and Hopkins, 2006). Whilst this dichotomous approach simplifies the result interpretation, it has been argued that, particularly for research into elite sport, the magnitude of the effect is more important than its statistical significance. Applied researchers, athletes and coaches would like to answer the question ‘How much does A affect B?’ rather than simply ‘Does A significantly affect B?’ (Buchheit, 2016).

Additionally, through null hypothesis significance testing it has been found that p values, and therefore study conclusions, are dependent on the sample size and large sample size studies can find statistically significant results, which may have little practical meaning (Batterham and Hopkins, 2006; Buchheit, 2016). Similarly, null hypothesis significance testing suggests that non-significant results, which may be due to small sample sizes or large variability, have no worthwhile effect even though differences may be practically very meaningful (Winter et al., 2014).

To counteract these issues, magnitude based inferences were used in the current thesis. Effect sizes and associated 95% confidence intervals were calculated and combined with smallest worthwhile change values established in Chapter 4 to establish magnitude based inferences for Chapters 5 and 6 (Batterham and Hopkins, 2006). From these results, it was possible for the authors to ascertain whether relationships and effects were meaningful or simply within the natural variation of the athlete and test rather than simply significant or not.

The utilisation of magnitude based inferences in the current thesis, to provide the meaningful effect on performance of any relationship/effect rather than simply the

significance of a relationship/effect is good example of why magnitude based inferences may be preferred to null hypothesis significance testing within the elite athlete applied research environment. This was well illustrated in Chapter 5 in which significant increases were seen across a season from July to April in various strength and power measurements across all playing age groups. However, when smallest worthwhile changes and effect sizes were compared, big differences were seen between playing age groups and ‘likely’ and ‘very likely’ increases were only seen for the U17 playing age group. If significance testing alone was used, the depth of information about training age group dependent variation across a season would not have been possible.

Additionally, through the capability to infer results in more detail, magnitude based inferences enable a coach or practitioner to view the costs and benefits of a particular decision and therefore, arrive at a more informed and educated decision which would not be possible with null hypothesis significance testing. This is illustrated in Chapter 6 of the current thesis in which ‘possible’ negative effects of match play were seen for Peak Power production on the day following a match play. In detail, it was established that match participation resulted in a 39% chance of having a negative effect on peak power production the day after a match. This level of detailed information gives a practitioner and a coach a better understanding of an athlete’s ability to perform maximally one day after a game and adjust individual training programmes appropriately.

Finally, a longitudinal advantage of using magnitude based inferences for a practitioner within an elite sport setting is that, once the typical error and smallest worthwhile change of a test are established, subsequent evaluations into the likelihood of change of an individual can be accurately completed. Therefore, through using magnitude based inferences on original research, continual evidence based recommendations for individuals are possible, which will continually improve applied practice (Buchheit, 2016).

8.6 *Future investigations*

As mentioned previously in this discussion, although providing a good base of research in elite soccer players, as it was only completed within 1 professional team future research could look at expanding this research to further validate its findings.

In particular, establishing playing position and playing squad dependent typical values across multiple squads and a larger cohort would add robustness to the initial findings in this study and act as an interesting comparison to see whether differing training methodologies at different clubs did have a significant effect on seated leg press performance.

To further the research completed relating to the variation across a season in lower limb strength and power performance, future research could evaluate the effectiveness of different strength and power training programming on training playing age groups across a season. Could the inclusion of strength and power sessions on days surrounding a match increase strength and power progression across a season in a playing age group such as the U21 group who are heavily involved in matches? Additionally, could different methodologies of strength and power training (eccentric overload training vs. Olympic weightlifting) have a differential effect on strength and power progression across a season also?

In a progression to the findings established in Chapter 6, further research is needed into whether any common strength and power characteristics can be established between individuals that have differing responses to match play. Could it be that those who consistently produce significantly higher power output than the average of the group are likely to suffer greater negative effects from match participation? Whilst this would associate favourably with injury burden findings in Chapter 7, due to low sample size, it was beyond the scope of the current thesis to investigate this adequately.

As the current thesis found low rates of left-right asymmetry in the current population of soccer players, future research should be aimed at investigating the validity of this through seated leg press performance. Similarly, further investigation into asymmetry in elite soccer is needed, for example comparing asymmetry between groups of elite soccer players that were not selected for professional contracts and/or sustained career limiting injuries in comparison to fit individuals who acquired professional contracts who be very interesting to evaluate the influence of asymmetry of the development of an elite soccer player.

Finally, as Chapter 7 of this thesis only found ‘possible’ associations between seated leg press strength, power and asymmetry measures and injury incidence, results in the

current thesis support the idea that injury is multivariate. Therefore, future research should look at combining multiple testing and monitoring data sources such as external GPS load monitoring, strength and power assessment, biological measurements etc. and subsequently looking at their multivariate affect on injury incidence and burden to gain a greater understanding of the combined effects of risk factors on injury.

8.7 Thesis Conclusion

The research completed in this thesis has provided a unique insight into the applicability of the Keiser Air420 seated leg press as a lower limb strength and power testing device in the applied soccer environment. The research established the reliability and consistency of lower limb strength and power performance of elite soccer players using the Keiser Air420. Playing squad and playing position dependent typical characteristic strength, power and asymmetry values were also established with an average bilateral power asymmetry of $4.3 \pm 4.1\%$ found. U21 playing age group, Centre Backs and Strikers were found to have superior strength and power output with all other playing age groups and position producing values comparable to the average of all players. U17 age group were found to have significant strength and power improvements over the course of the season, likely due to the increase from a part time to full time training schedule whilst U18 and U21 age group remained unchanged through the season. Likewise, asymmetry magnitude remained unchanged over the course of the season for all playing age groups. The Keiser Air420 was unable to establish significant changes were seen across any strength and power variables as a result of participation in match play. Despite this, large variation within the group was seen leading the authors to stress the need for individual screening and the use of multiple lower limb strength and power tests to accurately evaluate individual strength, power and asymmetry responses to match play. Finally, the Keiser Air420 was established as sensitive screening tool for injury burden by establishing that soccer players with higher strength and power output capabilities were at a significantly increased risk of days lost to injury despite no differences being seen in comparison to injury incidence. These findings emphasised the usefulness of screening players using the Keiser Air420 as well as exercising caution with players capable of high strength and power output during periods when injury

risk is greater. No correlations were found between left-right leg asymmetry and 'relevant' injury incidence or injury burden.

Overall, the current thesis has established the Keiser Air420 is an applicable testing and screening protocol for use with elite soccer players. It has established that tests can be considered reliable and has provided playing squad and playing position dependent typical characteristic values, along with limits of meaningful change, to enable practitioners to benchmark results and accurately evaluate longitudinal change. Despite establishing no correlation between bilateral asymmetry and injury risk, positive associations between increased lower limb strength and power and increased injury burden found in the current thesis also promote the use of maximal seated leg press testing as a screening tool for injury risk with elite soccer players.

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